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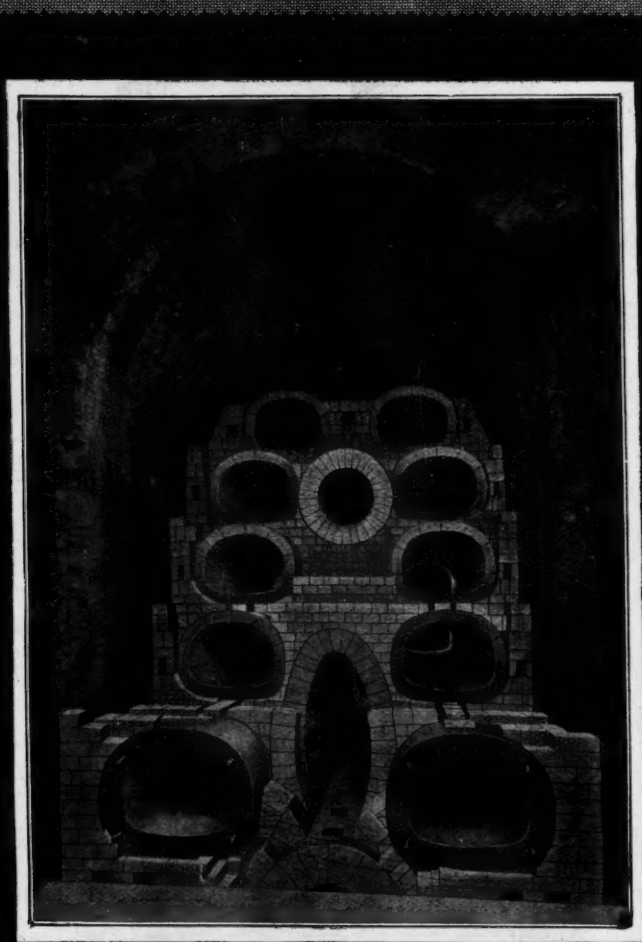

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REFRACTORIES FOR GAS-RETORTS, WITH SPECIAL REFERENCE TO SILICA.

By W. EMERY, of Stoke-on-Trent.

INTRODUCTION.

Among the mass of detail published on the subject of silica refractories, little can be found which is of any help to the hard-worked provincial gas engineer, who may be faced with the necessity of reconstructing his plant, and who wishes to advise his committee or his directors as to the refractory which will prove to be the most efficient and economical when adopted at his station.

I have had the privilege, through the kindness of many members of the Institution and of many of the large gas engineering contractors, of obtaining information from a number of installations in this country where silica retorts are in use, and I propose to introduce for your consideration some of the points and problems which have interested me during the investigations.

It is convenient to adopt the official classification of the Institution in referring to refractory materials; this classification describes as siliceous those materials in which the percentage of silica lies between 80 and 92, and as silica, those materials having a silica-content exceeding 92 per cent. Since vertical retort practice is definitely pledged to the use of silica or highly siliceous refractories, it will be more useful to members, whose aim is the impartial investigation of the properties of this material as a factor in engineering construction, to focus attention upon horizontal practice, and to see how the adoption of silica has advanced this type of plant.

The following claims have been made for and against silica materials:—

Advantages.

Increased rate of carbonization and throughput.
Longer life.
Rigidity and shape retained at high temperatures.
Heavier charges possible.
Resistance to abrasion.
Easily scurfed.
Not affected by ash in producer gas.
Less cracking.
Greater resistance to corrosion from salty coals.

Disadvantages.

Excessive expansion.
Special precautions required during setting.
Wear and tear due to alternations of temperature; spalling troubles.
Deterioration when shut down.
Fragility and tendency to disintegration.
Life under varying working conditions not established.
Capital outlay.

The available laboratory data relating to the various refractories referred to in the report are summarized in Tables I. and II.

TABLE I.

	A1	A2	A3	A6	A7
SiO_2	95·13	95·26	94·98	95·64	—
TiO_2	0·11	0·02	0·24	0·25	—
Al_2O_3	1·46	1·45	2·10	1·43	—
Fe_2O_3	0·43	0·42	0·70	0·68	—
MgO	—	0·23	0·10	0·08	—
CaO	2·55	1·61	1·72	1·50	—
K_2O	0·15	0·30	0·47	0·12	—
Na_2O	—	0·23	0·10	0·34	—
Loss	—	0·20	0·05	0·16	*
*Manufacturers will not release analysis for publication.					
True Sp. Gr.	2·37	2·43	2·44	2·37	2·34
Porosity	39·24	30·46	34·84	29·54	28·20
App. Sp. Gr.	1·44	1·69	1·59	1·67	1·68
Aft. Expans.	0·20	0·13	0·25	0·05	0·07
(2) True Sp. Gr.	2·35	2·40	2·42	2·36	2·32

(2) True Specific Gravities, carried out on the same test pieces after they had been subjected to the "after-expansion" test.

Carbonization and Throughput.—There is no doubt that silica retorts are very conducive to rapid carbonizing periods at high temperatures. This speeding-up has been mainly accounted for in terms of conductivity.

Conductivity.—The problem of the transmission of heat by way of the walls of refractory materials, *i.e.*, silica and fireclay retorts, is of primary importance to those engaged in the carbonizing industries. Unfortunately, the accumulation of data concerning this problem, obtained both from the laboratory and from the works, has brought much confusion and controversy. Although it is not my object to add to the controversial aspect of the subject, I should like to indicate certain factors bearing on the subject which may form the basis of a compromise between some very divergent points of view.

TABLE II.

	B1	B2	B3	B4	B5	B6B	B6R	B7	B8
SiO_2	88·70	84·46	90·08	74·40	81·60	84·2	86·31	75·5	81·80
TiO_2	0·86	0·86	0·40	0·60	0·70	—	—	—	0·62
Al_2O_3	8·35	11·35	6·26	21·50	15·01	—	—	—	14·51
Fe_2O_3	0·81	0·80	1·87	2·50	1·80	—	—	—	1·60
MgO	0·10	trace	0·05	trace	0·30	—	—	—	0·29
CaO	0·31	0·54	0·33	trace	0·20	—	—	—	0·85
K_2O	0·56	0·78	0·60	0·60	—	—	—	—	0·38
					0·80				
Na_2O	0·33	0·63	0·40	0·50	—	—	—	—	0·23
Loss	0·21	0·20	0·11	0·10	—	*	*	*	0·18
*Analyses relating to B6 and B7 not released for publication.									
True Sp. Gr. ..	2·50	2·50	2·47	2·67	2·58	2·59	2·52	2·55	2·62
Porosity	31·20	33·20	32·80	27·76	30·50	28·60	25·80	22·90	32·83
App. Sp. Gr. ..	1·72	1·67	1·66	1·93	1·79	1·85	1·87	1·96	1·76
Aft. Expans. ..	0·45	0·26	0·22	—	nil	0·12	0·31	—	—
Aft. Contrac. ..	—	—	—	—	—	—	—	0·37	0·16

The statement that "silica refractories have a much higher thermal conductivity than fireclay refractories" has made a wide appeal to gas engineers and managers. Some of the advertisements issued by interested firms are written very ambiguously; others give such a definite opinion as to suggest that this problem of heat transmission is finally settled, and that the results can be encompassed in a single, most simple sentence. One particular circular contains the following statement: "Silica material has approximately 16 p.ct. higher conductivity than fireclay at 1000° C." Unfortunately, gas engineers, who are always striving for increased thermal efficiency, are likely to be impressed by such definite expressions of fact.

The published data concerning the thermal conductivity of refractory materials do not reveal any striking differences in the values for silica and fireclay up to 1000° C. There is, however, one quite notable exception, published by Prof. Cobb[1], in which he reports a marked increase of diffusivity of silica as compared with fireclay at the temperature previously mentioned. Middleton[2] expresses doubts about the supposed higher values of silica at 1000° C., but states that at higher temperatures its conductivity becomes considerably greater. In other words, in carbonizing plants where relatively low temperatures are employed, there is little to choose between silica and fireclay material on the ground of thermal conductivity alone. In an extension of his work on conductivity, Green[3] notes that the rate of thermal conductivity and diffusivity with temperatures in the neighbourhood of 1200° C. is somewhat greater in the case of three well-burned silica bricks than in the case of an average of fireclay materials. His results are important, inasmuch as they suggest a confirmation of the works' results previously quoted.

It is essential to have a clear conception of what is implied by the term "thermal conductivity" in order to appreciate the commercial value of the data submitted by various workers. This aspect of the problem has been dealt with somewhat fully by Green[4] in a previous communication to the Institution. Since it is material to the development of the present argument, I must recapitulate some of the more salient features of the paper.

Consider the formula:

$$K = kcs,$$

where K is the coefficient of thermal conductivity at a temperature of θ°C,

k is the coefficient diffusivity at a temperature of θ°C

c is the apparent specific gravity.

s is the specific heat at a temperature of θ°C.

Such a formula can be used as the basis of comparison

1 Dougill, Hodsman, and Cobb, *Journ. Soc. Chem. Ind.*, **34**, 465, 1915.
2 Middleton, *Trans. Cer. Soc.* **22**, 173, 1922-1923.
3 Green, Private communication.
4 Green, *Trans. Inst. Gas Eng.*, 1921-2, p. 195.

of the thermal conductivity of silica and fireclay. The product *c.s.* may be called the heat capacity per unit volume of the material. The experimental evidence of Bradshaw and Emery[5] shows that the specific heat of silica is almost identical with that of fireclay up to temperatures of 1400° C.

This fact shows that the apparent specific gravity of silica or fireclay material is a direct measure of the heat capacity. The apparent specific gravity of silica material is almost invariably less than that of fireclay material (*e.g.*, 1·63 for silica and 1·95 for fireclay material), so that the heat capacity per unit volume of silica is less than that of fireclay.

"Diffusivity" or "temperature conductivity" is essentially concerned with rate of rise of temperature, and, in consequence, it gives some definite criteria for those heating units such as gas-retorts, in which the rate of rise of temperature is of more importance than the total heat-work effect. The coefficient of diffusivity may be defined as the rise of temperature produced in 1 cc. of the substance by one calorie in one second through one sq. cm. of a layer one cm. thick, having a temperature difference of 1°C. between the two faces.

To illustrate the significance of this conception, I may be allowed to quote an interesting experiment by Prof. Tyndall. He showed that a temperature wave travels more quickly in bismuth than in iron, although the thermal conductivity of the latter is nearly six times greater than that of the former. The application of this conception to our study is illuminating. There is little difference between the diffusivities of silica and fireclay materials below 1000° C., although the evidence previously mentioned indicates that the diffusivity at the higher temperatures of practice is somewhat greater in the case of silica bricks. Herein may lie the clue to the opinion of many engaged in this industry concerning the problem under review.

As has been previously indicated, the thermal conductivity at a specified temperature is determined by the product of the heat capacity and diffusivity. Since the heat capacity of silica is lower than firebrick, the diffusivity of the former must be much greater in order to obtain identical conductivities. Below 1000° C., this increase in diffusivity is not generally noted, which leads me to believe that, in general, firebrick is probably the better conductor of heat at lower temperatures.

In the paper included in the Joint Committee's Report to be presented at this meeting, on the influence of texture on heat transmission, the author, Mr. A. T. Green, suggests that the variations are primarily due to the disposition, size, and orientation of the pores within the refractories. Further, it is suggested that greater values of increase in the transmission of heat are to be expected at high temperatures, together with the property of greater permeability to gases. This suggestion has an interesting bearing on the comparison between silica and fireclay materials.

I have examined a large number of refractories of all types after they have been used in commercial heating units, and I conclude, as a result, that there is less alteration in the porosity of silica goods (see table) during use in gas installations than is the case with fireclay materials.

Dale, in a previous communication to Bulletin No. 7 of the British Refractories Research Association, has studied the question, not from a heat transfer point of view, but in connection with the refractory-under-load test. He states that the orientation of the pores in refractories is considerably modified when subjected to load between 1300° and 1400° C. He has also examined fireclay refractories, which show a decrease in porosity ranging from 4 to more than 15 p.ct., whereas in no case do 95 p.ct. silica refractories show any marked decrease in porosity. I would suggest that the maintenance of porosity while the refractories are in actual use is a factor requiring very close attention.

I have on view representative samples of the retort material now available for gas-works. The polished surfaces of these bricks show clearly marked differences in texture. For example, compare A7 and A1. The porosities of these are 28·71 and 39·24 respectively. Sample A6, which occupies an intermediate position between A7 and A1, possesses a porosity of 29·54. The manufacture of silica goods has, however, undergone a decided development. At an early period the texture of the goods delivered to gas-works was of that general type which had given good results in metallurgical operations, but in many cases the firing of these goods was far from satisfactory. At the present time, the average grain size is less, the mass is much more homogeneous, and the firing more satisfactory. It is clear, then, that the makers realize the importance of texture and firing conditions as at least equal to that of chemical composition.

Mr. W. B. Leech[6] has pointed out how difficult it is, under working conditions, to assess the relative conductivities of refractories. He has assembled considerable data concerning the internal and external temperatures of a great number of retorts, and, as a consequence, asserts that the use of silica retorts increases the internal temperature 60°C., where the combustion chamber temperatures are in the neighbourhood of 1400°C. If it is assumed that (1) the chamber temperature remains constant and (2) the same amount of heat is passing through the retort in the two cases, *i.e.*, silica and firebrick material, it means that the conductivity of the silica in these circumstances is 30 p.ct. greater than that of the firebrick.

With the exception of this case, I have been unable to obtain any reliable data on the internal temperatures prevailing in horizontal retort practice. I can appreciate the diffidence displayed by various engineers in passing on for publication any information regarding conductivity. However, since it may be that the next development in large town-gas installations will be the adoption of chamber practice, the observations and data published by Middleton, Townend, Hebden and others will be applicable to the gas industry. I have elicited one or two interesting facts having a distinct bearing on the present arrangement. Mr. Thompson, of Messrs. Drakes Ltd., who has had a unique experience with the use of silica retorts, reports that, in his opinion, working heats may be obtained more rapidly in new silica than in new fireclay retorts.

The following incident occurred at a Northern gas-works. A setting of silica retort material had been installed, and while the heats were being raised, several of the "lungs" gave way, with the result that the normal working temperature could not be attained. This occurred during the "peak-load" period, and consequently the setting had to be worked. The management were definite in their opinion that it would have been very difficult in like circumstances to have carbonized in fireclay retorts, and they estimated that, even if it had been possible, a further four hours would have been necessary.

It is clear that the increased carbonizing temperatures now prevailing must lead to an increased carbon deposit. Nicholson[7] and Warren[8] have already discussed this problem dealing with the effect on porosity. Laboratory data are lacking as to the behaviour of carbon in the pores, but Cobb[9] has stated that, in his opinion, the infiltration of carbon into the pores results in increased thermal conductivity.

The following data have been obtained concerning the scurf deposit taken from a gas-retort, and may be of interest in connection with the effect of this scurf on heat transmission.

True sp. gr.	App. sp. gr.	Porosity.
2·12	1·78	16·0

In assessing the relative thermal efficiency of silica material, the fact that the general adoption of more completely filled retorts and higher temperatures has more or less coincided with the extended use of silica retorts, must not be overlooked.

A summary of the available data suggests that the heat transfer will be more rapid in silica at the high temperatures now in use, *e.g.*, 1350° to 1450°. Evans, in his recent series of lectures, has shown that the temperature prevailing in the interior of retorts during the initial period after charging is all important. If the assumption be valid, that the diffusivity and thermal conductivity of silica are higher than those of fireclay, then it is obvious

[5] Bradshaw and Emery, *Trans. Inst. Gas Eng.*, 1919-20, p. 101.

[6] Leech, *Trans. Inst. Gas Eng.*, 304, 1922.
[7] Nicholson, *Gas World*, **80**, 14 C.S., 1924.
[8] Warren, *Gas World*, **78**, 183, 1923.
[9] Cobb, Loc. cit.

that the first-named refractory will give better results. It must be remembered that the infiltration of carbon into the pores of the material will invalidate any laboratory measurements on the conductivity of the "pure" refractory.

It is interesting to note that the constructional engineers, who are responsible for the modern vertical installation, do not suggest that increased thermal conductivity is obtained by the use of silica constructions; rather do they stress that improvements may be looked for owing to the increased stability at high temperatures.

Longer Life.—The life of the retort is a factor which is of great interest to the gas engineer. A long life means lower capital charges, a considerable reduction in carbonizing costs, while in the provincial works the engineer is not always faced with the worry of calling in contractors and engaging bricklayers for the purpose of renewals. It is natural, considering that the utility of silica retorts has only been realized during the last ten years, that reliable data relating to the life of such constructions used in town-gas installations are somewhat meagre. Fortunately for the industry at large, Mr. Leech and his staff at Beckton have carried out very extensive works' research with silica settings and their published results have set a standard of comparison for the industry. Other gas managers and engineers have made extended trials with a similar material, but at present the full results are not yet available for publication.

Mr. R. G. Shadbolt states that silica retorts have a life at least one-third longer than moulded fireclay in plants where hand stoking is adopted.

The following data relating to retorts other than silica are included, so that one can judge of the life of modern fireclay and siliceous materials compared with that obtained by the Beckton methods.

Mr. Firth[10] has already communicated a note relating to the use of siliceous and silica retorts, and, in reply to a letter from me, states that the siliceous retorts which he uses are built up of three segments. The retorts are in very good condition after gas-making for 219 days, during which period 263 tons of rough slack per retort have been carbonized. The makers of these retorts say that segmental retorts are preferable, because, owing to the smaller sections, greater uniformity during the manufacturing operations can be ensured.

Messrs. Koppers have furnished some useful data relative to the use of their chamber ovens for town-gas manufacture in the United States of America. Some of their ovens have been in continuous operation for fifteen years without any repairs, so that they say it is impossible to suggest what the probable life will be. The average flue temperature is 1350° C., and the net carbonizing period is 11 hours 5 minutes.

Mr. T. Glover allowed me to visit the Bishop's Bridge works at Norwich at a period when a house containing sixteen beds was down for overhaul. The settings are all of the Klonne generator type. Silica bricks are used in the combustion chambers and also in the centre of the cross walls, and 83 p.ct. siliceous bricks on the outside of the setting. The retorts examined were of the siliceous type, Serial No. B6. The works' officials stated that they had been worked for 1853 days at an average temperature of 1315° C., the weight of charge being 14 cwt., which is carbonized in twelve hours, and that the total throughput per retort was 2500 tons. I would suggest that, when the retorts have been refronted, they will last for a considerable period. The above results suggest that well-burned siliceous segmental retorts are eminently suitable where moderate temperatures are adopted.

Mr. S. N. Wellington has furnished data relating to the inclined chamber plants on the Continent and at Darwen. He states that the capacity of the chamber constructed of Stettiner silica is 8 tons per charge; the working flue temperature ranges from 1300° to 1400° C. At Hamburg they approach 1500° C. and the make is over 15,000 c.ft. of straight gas (c.v. 510–520 B.Th.U. gross) per ton, with English coal. With regard to the Darwen plant, the chambers are built up of the Stettiner fireclay material, and have been in use for nine years. The installation has given exceptionally good results, and the refractories are still in good condition. It is the considered opinion of Mr. Wellington that silica material is the only refractory which should be used in coke-ovens and gas-works, if progress is to be made.

It must be admitted that the manufacture of fireclay and siliceous retorts has not reached finality as regards improvement. Possibly competition will stimulate the manufacturers of the latter type in the direction of improved texture and the development of a refractory, which, while not remaining rigid at the highest temperatures, will be more suitable than silica for the engineers who still prefer to carbonize at moderate temperatures.

Rigidity and Maintenance of Shape at High Temperatures.—Silica refractories will stand higher temperatures under conditions of load than fireclay goods. It is therefore a natural consequence that silica retorts should replace the older types of siliceous or fireclay material. In spite of this, however, the illustrations which have been published recently, showing the condition of fireclay retort installations after an extended run at relatively high temperatures, suggest that the problem of choosing a suitable refractory material is not quite so simple as it appears at first sight.

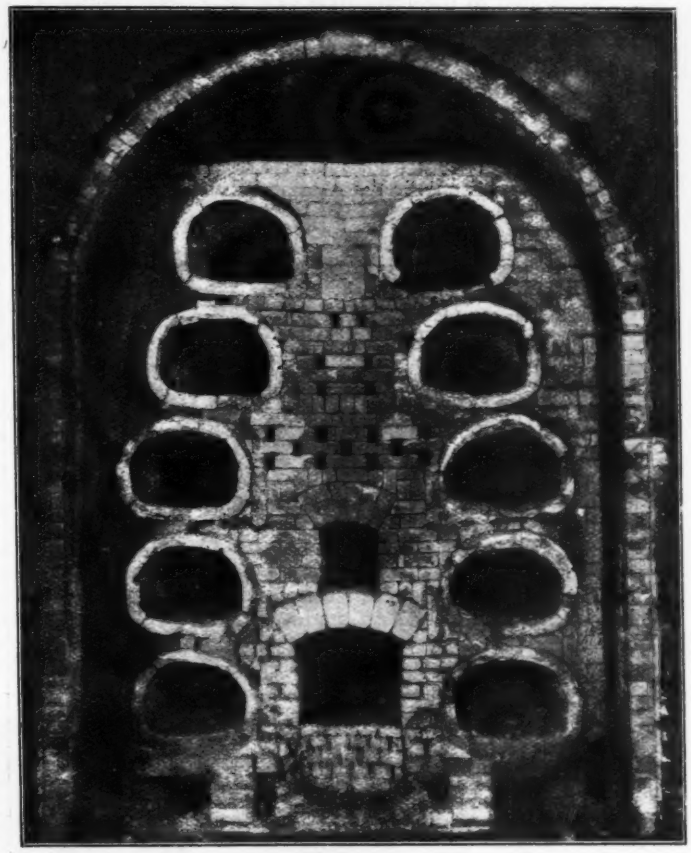

Fig. 1.—Moulded A4 siliceous retorts after 2660 days (Drake's setting). A3 silica in chamber and centre of cross walls; fireclay remainder.

The following factors have a direct bearing upon the life of the material:

1. Type of setting—with special reference to the nature of the cross walls and the proportion of retort covered by same.
2. Working temperatures, with indication of possible fluctuations.
3. Composition and physical properties of retorts.
4. Type of machine.
5. Cross-sectional design and size of retorts.
6. Proportion and type of ash present.
7. Throughput per unit.
8. Liability to form scurf.

Mr. Bromley, the Engineer and Manager of the works at which the exceptional working of fireclay retorts mentioned above has been obtained, kindly gave me permission to visit his plant. Having regard to the fact that these retorts are made of fireclay, it is interesting to know that they have operated for a working period of 2660 days, carbonizing 20 cwt. charges in 12-hour periods, with a stoking machine of the Drake's type in use, and with abnormally high working temperatures (for fireclay) of 1370° to 1420° C. This latter figure has been subjected to independent verification by many persons. I have no

[10] Firth, *Gas Journ.*, 165, 641, 1924.

other record of fireclay retorts giving such consistently good results, but possibly members of the Institution may have confirmatory evidence at other plants (see fig. 1).

This is a case of a refractory material which, judged by the usual standards, is exhibiting abnormally good qualities. Considering the matter from all sides, I came to the conclusion that the behaviour under load is a prime factor in the case. I have discussed the matter with Mr. A. J. Dale, B.Sc., and he puts forward what appears to be a very reasonable explanation. During some recent work on the softening of refractories under load, Mr. Dale carried out two distinct sets of experiments:

(1) Determination of the nature of the subsidence occurring under load before the temperature at which complete failure takes place is attained.

(2) Determination of the rate and amount of subsidence under load at a constant temperature of 1350°C.

As can be readily seen, the latter test provides a measure of the rigidity of refractories at temperatures well within practical working limits. His results, which will be communicated to the Institution at a later date, suggest that certain classes of refractories remain fairly rigid under load at high temperatures not far removed from those at which complete breakdown occurs. Other types deform at relatively low temperatures. While silica belongs to the first class of materials, fireclays in general belong to

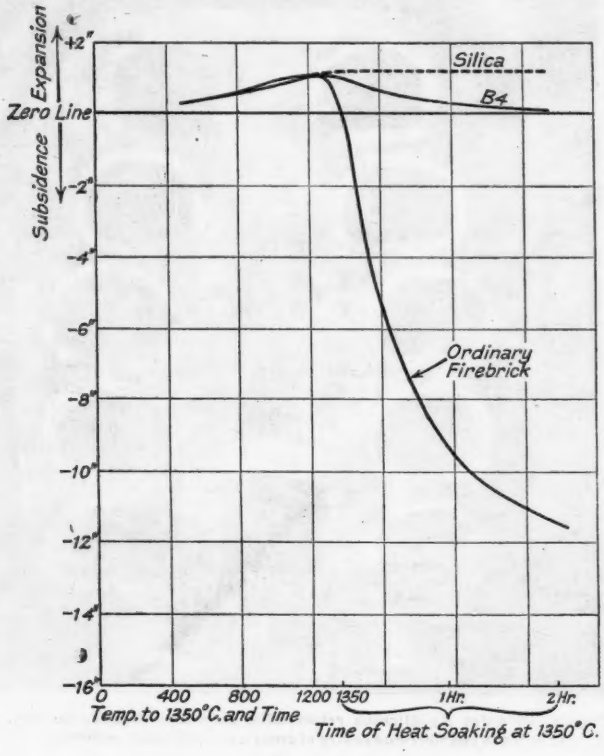

Fig. 2.

the second, so that a possible explanation lies in the fact that this particular fireclay (and possibly others) are peculiar in maintaining a "silica" type of structure at elevated temperatures. An alternative explanation lies in the fact that the maintenance of porosity at elevated temperatures may allow the infiltration of carbon to proceed to such an extent that the retort may become a carbonized clay substance, which possesses a higher refractory value than normal clays. This subject has already received attention by Bradshaw and Emery and Lessing, and, of course, has formed the subject matter of a patent by J. Smith.

The following data relating to the working behaviour of some of the fireclay and siliceous retorts have been passed for publication by Mr. W. B. Leech (see figs. 3 to 7, plate 1):—

Heavier Charges.—I have been unable to elicit much information which would lead me to believe that, other factors remaining constant, the introduction of silica retorts would enable heavier charges to be burned off in unit time. This is natural, inasmuch as the general

SUMMARY OF OBSERVATIONS MADE DURING A VISIT TO THE BECKTON WORKS.

House No.	Serial.	Make.	Temp °C.	Working days.	
2	B7	Segmental	1380	520	Very good conditions.
	B4	Moulded	"	"	
3	B8	Segmental	1st yr. 1325 2nd yr. 1350 3rd yr. 1400	940	Setting was down, the retorts were examined from combustion chamber side, and apart from a covering of dark brown slaggy material they are in excellent condition.
5	B4	Moulded	1370	1530	Setting had been let down because the two top retorts had given way. Whereas eight full sets of silica retorts in same house were in excellent condition.
6	A1	Segmental	1410–1420	280	"All silica settings" total of retorts. The behaviour of these two houses will probably decide future practice.
7	A1	Segmental	1410–1420	230	
8	A1	Segmental	1350–1350	530	
	B6	Moulded	1350–1360	530	Good condition.
	B7	Moulded	1350–1360	530	
12	A1	Segmental	1380–1390	180	10 Beds.
	A2	"	"	"	21 "
	A7	"	"	"	2 "
	B6	"	"	"	7 "
	B8	"	"	"	2 "
					All in perfect condition, excepting in one bed, where top retorts were pushed up as in figs. 3-5 due to excessive expansion of cross walls.
12	A1	Segmental	1400	2150	No distortion—excellent shape. See figs. 6-7.

practice during the last ten years has been to carbonize with full retorts, irrespective of their type. However, Mr. Chew has had a battery of silica retorts in use for 410 days, and he reports that: "The fuel used is 75 p.ct. slack together with 25 p.ct. screened and unscreened coal. The carbonizing period is 12 hours, but we are obtaining heavier charges with silica retorts."

Abrasion.—The silica retorts which have been inspected have withstood scouring action very well. It is of interest to note that the silica retort manufacturers emphasize the fact that their goods are specially toughened, in order to resist abrasion. Well-fired fireclay and siliceous retorts are not lacking in this respect.

Mr. Morrison whose experience with silica and siliceous goods extends over a period of twenty years, states that he has had under close observation composite retorts, in which the sides and arches were constructed of silica and the base of fireclay. In some cases the fireclay did not withstand the scraping effect of the rakes and pusher heads.

Scurfing.—There is no agreement between the users of silica retorts on the subject of the deposition of carbon and the removal thereof. In a general way, the removal is mainly effected by the cooling and burning effects of air currents. It would be of interest to ascertain the behaviour of silica in smaller works where "stop end" retorts are in use, since under these conditions more mechanical treatment is required to remove the scurf.

Ash.—While at the Beckton works, I examined a setting which had been worked for 21 days and then shut down; one tier was built of silica, and the remaining tier of siliceous material. The differences, when seen from the combustion arches, were very marked. The silica retorts were substantially as set, whereas the siliceous ones were covered with a brown, semi-glazed mass, obviously due to the interaction of the ash and refractory. It should, however, be noted that this tendency to become covered with a semi-glazed mass soon after being put into use is not necessarily a criterion of the quality of a refractory, for, in many cases this coating forms such an impervious mass as to prevent further trouble.

Cracking.—It is admitted that, in general, moulded fireclay retorts exhibit a tendency to crack after a comparatively short life, as compared with segmental silica retorts. This fact, however, cannot be accepted as evidence that silica is more resistant to cracking than fireclay.

In order to obtain a real criterion, segmental or moulded refractory material of each type should be compared (see Fig. 8, plate 1).

Corrosion.—Mr. Foxwell, M.Sc., on behalf of Messrs. Koppers Ltd., has furnished me with the following

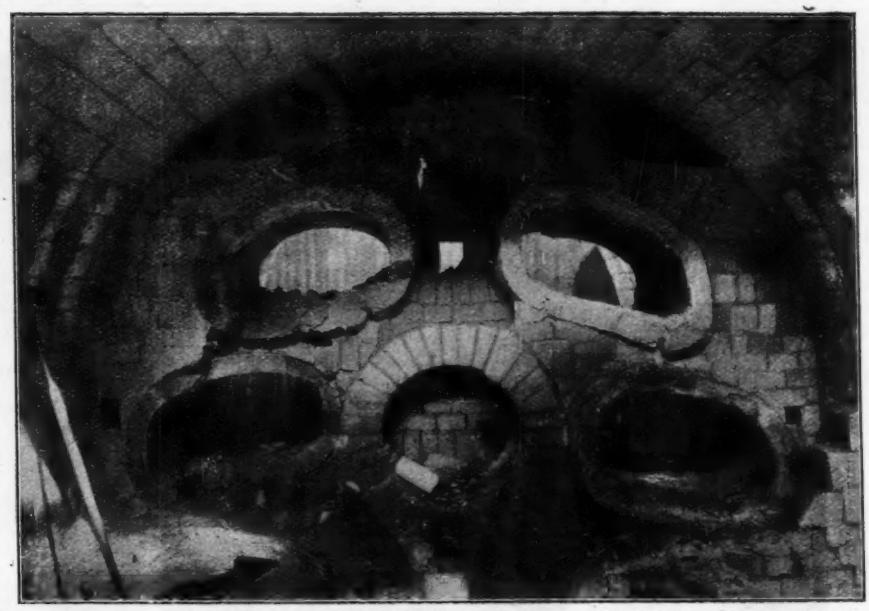

Fig. 3.—BECKTON. MOULDED FIRECLAY RETORTS AFTER 940 WORKING DAYS. A1 SILICA IN COMBUSTION CHAMBER; STOURBRIDGE FIRECLAY IN REMAINDER.

interesting note relating to the effect of sodium chloride on refractories :

"I have examined the action of salt on bricks and while, of course, most of my observations may not be given, I may say that I have found that silica, whether as quartz, cristobalite, or tridymite is attacked by fused sodium chloride, with formation of sodium silicate, although this action is not very rapid. On the other hand, if clay is taken, the action of the salt is to form a compound containing about 28 p.ct. of Na_2O, which cannot be washed out by water or acids. I do not know whether any explanation of the immunity of silica brick has yet been given, but although I have no experimental evidence to back up my suggestion, it has always seemed to me possible that the lime has a great deal to do with it. It may be that a lime-silica complex is formed which acts as a protective coating over each of the silica granules. There is some evidence for my view in that we have found in practice that a brick containing 91 p.ct. of silica, but with no lime, failed in under a year, whereas a brick with 95 p.ct. of silica and lime-bound has stood successfully for many years in the same ovens carbonizing the same coal."

DISADVANTAGES.

Excessive Expansion (reversible, or temporary, and permanent).—The nature of the expansion data, which are supplied to the constructional engineer by the physicist as physical constants of silica material, deserve a close study. When refractory goods are heated in industrial furnaces, they undergo two distinct alterations in their linear dimensions. The first occurs at relatively low temperatures, and if the refractories are cooled to normal temperatures after this heating, they return to their original size—hence the term reversible or temporary expansion. In other words the property in question is the unavoidable thermal expansion common to most solids when heated. Secondly, when heated to higher temperatures, a series of changes occur, the nature of which varies with the chemical and mineralogical composition, texture, and previous heat treatment of the goods, either at the brick works or during service. These modifications are irreversible or permanent. In the case

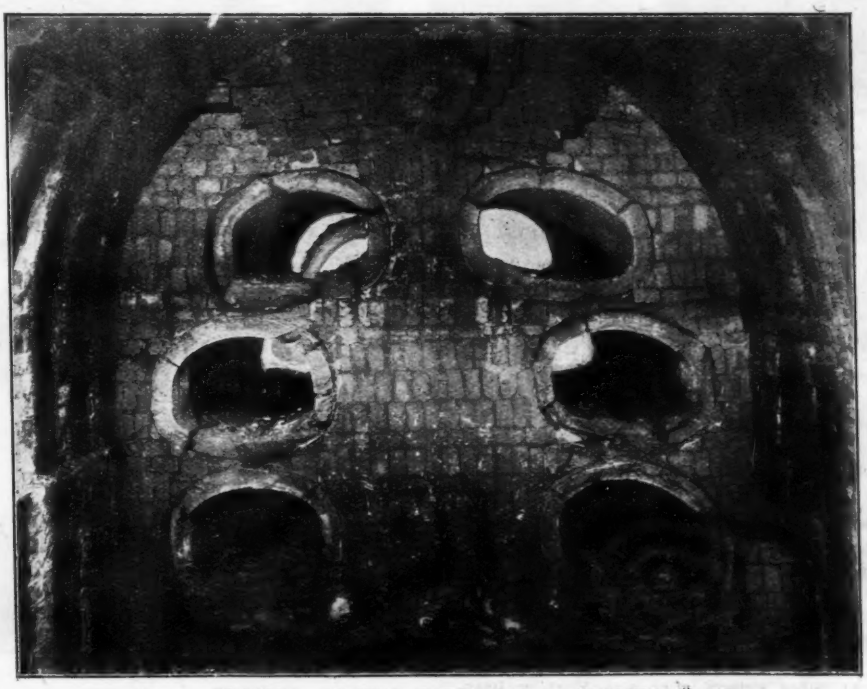

Fig. 4.—BECKTON. ANOTHER BED AFTER 940 WORKING DAYS.

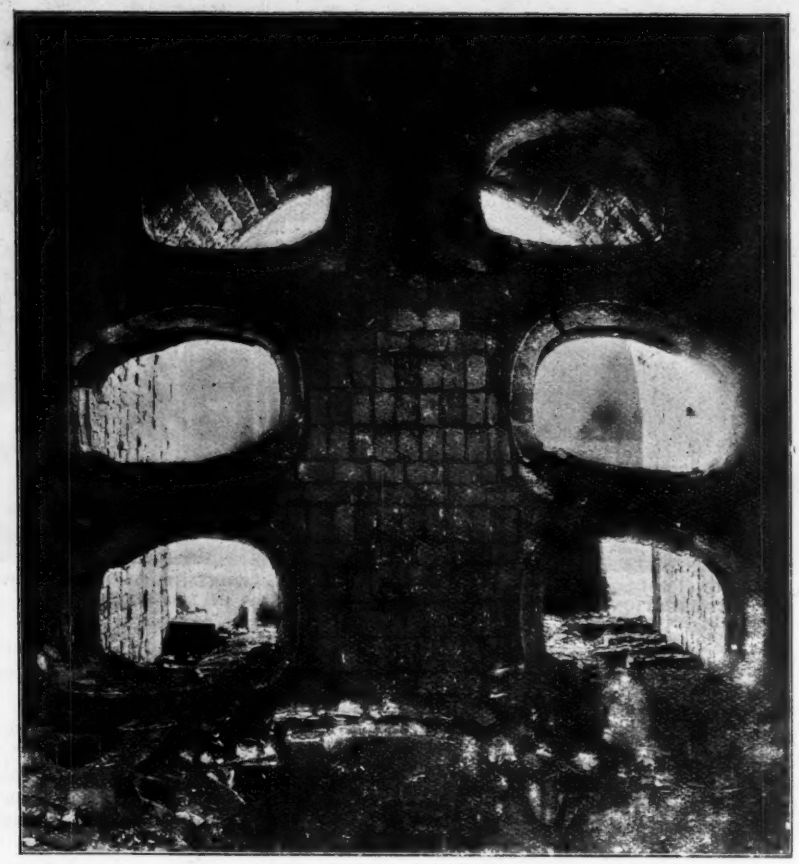

Fig. 5.—BECKTON, ANOTHER BED AFTER 1170 WORKING DAYS.

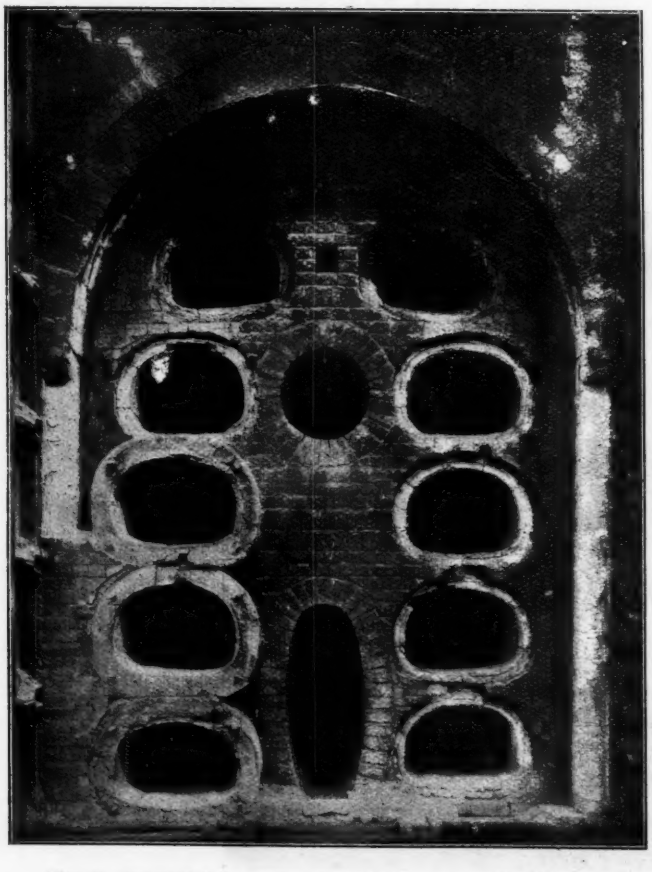

Fig. 6.—Segmental A1 Silica Retorts after 2150 Working Days. A1 Silica in Combustion Chamber; Stourbridge in remainder.

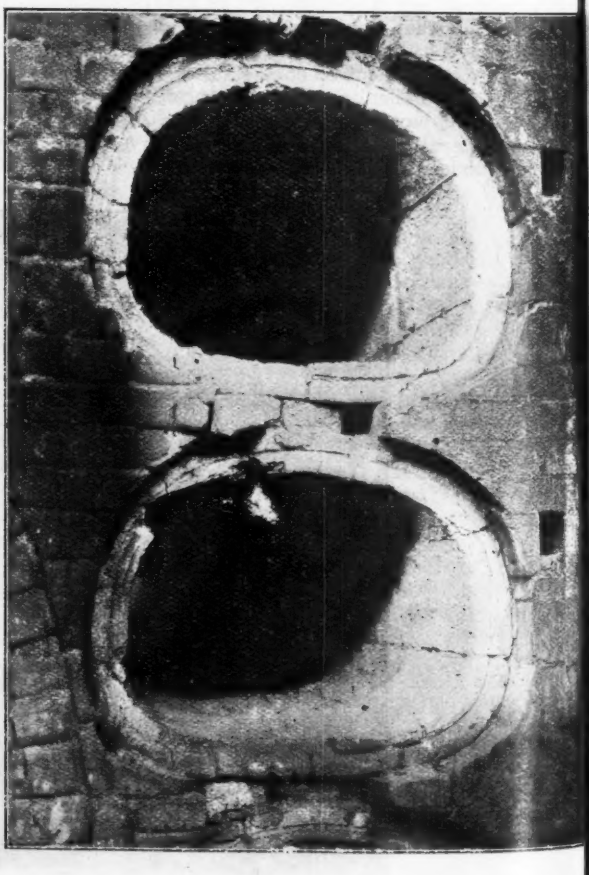

Fig. 7.—Enlarged View of Second and Third Tiers, in Fig. 6.

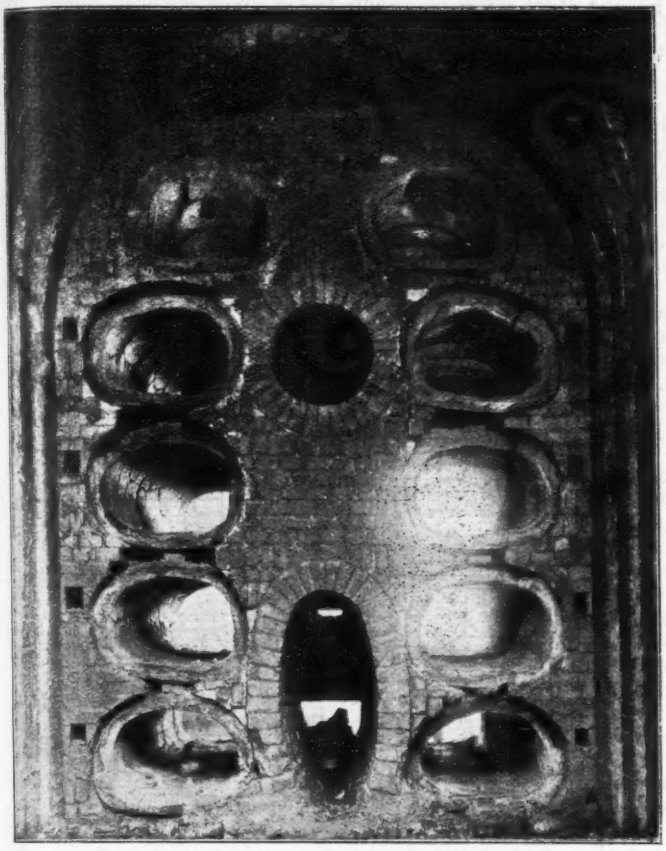

Fig. 8.—Beckton. Another Bed after 2150 Working Days.

of a good silica rock, it can be said that the permanent linear alteration is always an expansion, and is accompanied by a decrease in specific gravity. Similarly the normal variation in fireclay is a permanent contraction. When fireclays are hard burned, there is a slight increase in the specific gravity.

Dr. Mellor[11] and other workers have carried out investigations on the volume changes occurring in firebricks with the "Coppée" apparatus, which involves the use of full sized 9-in. bricks. Other academic workers in many countries have reported values in close agreement with those given by the use of the "Coppée" dilatometer, but in these latter cases the tests have been on a laboratory

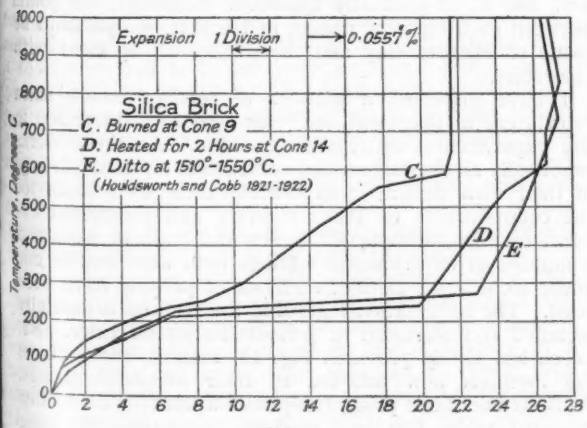

Fig. 9.

scale only. For our purpose it will be convenient to summarize some of the results reported by Houldsworth and Cobb[12]. During the heating of a raw unburned fireclay, there is a steady thermal expansion, until a temperature of approximately 540° C. is reached; the rate of expansion is accelerated between 570° and 600°; above 650° C. no further increase occurs. Well-defined permanent contractions occur at 880°, 950°, and 1080° C., which is the upper limit of their experiments. They have examined the behaviour of a silica brick which had been fired previously to Cone 14. Starting from the cold state, it was found that the length increased regularly up to 200°; from 200° to 250° C. an extremely rapid expansion occurred amounting to 0·75 p.ct. From 250° to 550° the sample expanded regularly, followed by a more rapid rate of expansion between 550° and 600° C. All the low-temperature changes are temporary, and amount approximately to 1·5 p.ct. Further irreversible and permanent volume increases were noted at the higher temperatures.

I am indebted to Messrs. Woodall, Duckham, Ltd., for the following information:

> "With regard to the expansion of silica settings as compared with fireclay, we find that a fireclay retort 26 ft. in length has an expansion from cold to a working temperature of 1290° C., of about 2 in, while a retort of the same length constructed with a central zone comprising 14 ft. of silica expands approximately 3½ in. up to 1400° C. After three months working at this temperature, the total expansion from cold becomes approximately steady at 3½ in. Owing to the fact that, during the warming up stages the total expansion is of a composite nature, *i.e.*, the temperature of the fire-clay work above and below of the silica and the temperature of the upper part of the silica zone being higher than the bottom, it is difficult to give any definite figures relating to the expansion of the silica at various temperatures. The above figures indicate a total expansion of the silica of approximately 1·4 p.ct. for the 3½ in. rise (probably comprising 1·2 p.ct. reversible and 0·2 p.ct. permanent), and a further 0·1 p.ct. permanent, making a total of 1·5 p.ct. for the 3½ in. rise. From our observations, approximately 70 to 75 p.ct. of the total expansion of silica settings takes place during the warming up stages and before any colour is visible in the combustion chamber."

The present writer, as a result of works experience, suggests that it is possible to produce firebricks which have zero volume changes when worked at moderately high temperatures. It should be recognized that, in this direction, the firebrick manufacturers have made rapid progress. It is impossible to lay down a definite percentage, type, or grain size of silica admixture to a fireclay, as being required to effect the purpose. However, once a standard has been decided upon, uniformity of grading, homogeneity, and firing treatment require constant supervision, if satisfactory results are to be obtained.

The firing of the refractories is undoubtedly the factor which decides their behaviour in use, since this regulates the permanent volume changes. Probably everyone present has had experience with fireclay retorts which have lost their shape, even when worked at relatively low temperatures; in most cases this defect would not have occurred had the heat work in the oven been greater than that imposed upon the retorts during use.

A number of substances such as lime, pyrites, &c., have a catalytic effect in speeding up the conversion of silica into tridymite. These materials, however, have the disadvantage that they lower the refractoriness, and as a result they cannot be used in those cases in which the goods are to be used under stringent conditions.

In the production of gas-retorts, however, it is possible, and in my opinion advisable, to make use of such admixtures in order to ensure more complete conversion, with its accompanying reduction in permanent expansion. In some instances the silica retort manufacturers use one mixture only, and that the one most suitable for the roof of steel smelting furnaces. However, it is interesting to know that other firms recognize that the gas industry demands specialized refractories, and have made the

[11] Mellor, *Trans. Inst. Gas Eng.*, 1917.
[12] Houldsworth and Cobb, *Trans. Cer. Soc.* **22**, 111, 1922; and **21**, 24, 1921–2.

necessary modification in order to produce goods likely to give the best results in town gas-works.

Many instances have been cited with respect to the ill-effects due to volume changes of silica cross walls. Mr. Leech has furnished pictures from which Figs. 3–5, Plate 1, have been prepared. At Beckton, I saw a similar defect in which the up-throw was about two inches, and this would probably increase as the high temperatures were maintained. The author is convinced that some of the alleged failures of moulded fireclay retorts have been due, not to the poor quality of the retort, but rather to the use of underburned silica bricks and blocks in the superstructure and cross walls.

Summarizing, it can be said that, with all types of refractories, the reversible thermal expansion is unavoidable; but the manufacturers of refractories have a modified control over the extent of the permanent expansion, and since it is the latter which is of vital importance to the user, it is the maker's responsibility to see that the point has proper attention.

It is obvious that the user must have some means of checking the quality of the goods he has received, and a test which will indicate whether the firing has been satisfactory is most desirable.

Consequently the standard after-expansion test has been adopted, and up to the present has probably been satisfactory. However, it may be that, as more laboratory and works data become available, other tests will be substituted. For silica refractories several alternative proposals have been made: these can be broadly divided into three groups:

1. Methods involving the micro-examination of thin sections. (See appendix to present paper.)
2. Methods involving the determination of refractive indices. (Houldsworth & Cobb).
3. Methods involving the determination of specific gravity.

It has been shown that, when a series of refractories has approximately the same percentage of silica and of lime, the true specific gravity is a direct measure of the firing treatment, and this, in conjunction with porosity, provides an indication of the probable expansion when put into use in industrial furnaces.

Fortunately the composition of the available silica retort materials does not vary very much, hence determination of specific gravity is very useful. A specific gravity can be quickly and accurately determined without the use of elaborate apparatus, and I would suggest a more extended application of this method. Middleton has shown that silica bricks having a standard mixture and fired in industrial kilns to—

1380° had a specific gravity of 2·43,
1430° had a specific gravity of 2·35,
1530° had a specific gravity of 2·23.

Restated, this means that, with an increase in the firing temperature of 150°, the decrease in permanent expansion was reduced by 1·3 p.ct. Making due allowances for the slight differences which may occur with other types of silica rocks, the above results may be taken as representative figures. The permanent expansion in practice is considerably greater than the theoretical, owing to the reorientation of the material.

This aspect of the behaviour of silica materials has been dealt with at length in order to make it clear that the most objectionable feature, from a constructional point of view, is amenable to improved manufacturing methods. In general, the improvement in quality is very marked; the manufacturers of silica refractories must not be content with anything but the best. In one case brought to my notice some silica segments were badly cracked; in fact, in order to complete a bed that was urgently required, the management were passing all goods with a maximum crack of 1 in. in length, relying, of course, on the support afforded by the cross walls to obviate danger.

At one works, I saw large batches of siliceous segments that were obviously underburned. It should be realized that the modern gas engineer is more conversant with the properties and behaviour of refractory materials than was the case some years ago, so that the manufacturer has to exercise a certain amount of discretion before he releases goods of inferior quality from his works.

The contractor is not only concerned with the expansion of the retorts and walls, but also with the increased stresses set up in the superstructure by the permanent expansion of the silica blocks at the higher temperatures. Messrs. Robert Dempster, Ltd., have taken out a patent which is of interest. The keystone of the producer arch is reinforced in such a manner as to provide a super-imposed or inverted abutment for support of the combustion arches.

Fig. 10, Plate 2, shows the lay-out of the arch and combustion chamber. It is obvious that, by the use of these blocks, the distance between the "legs" can be reduced; or, in other words, a more elliptical combustion arch can be built.

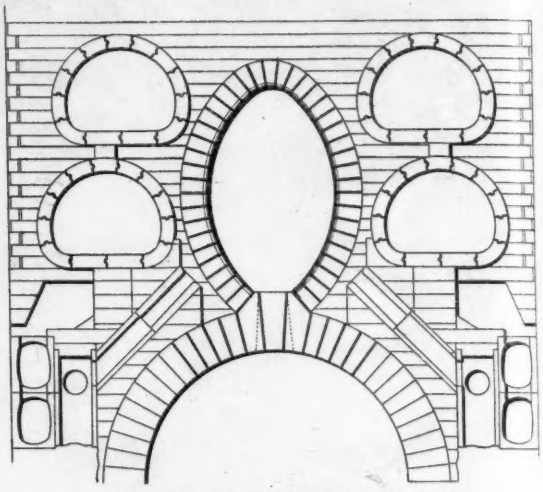

Fig. 10.—Dempster Keystone Producer Block.

Special Precautions required during Setting.—Considerable trouble has been experienced in making allowance for the peculiar expansion which takes place in silica constructions on heating. This trouble is solely due to the fact that constructional engineers have not had, as yet, the same length of experience with silica materials as they have had with fireclay. As soon as the necessary experience in applying the physical laboratory data furnished in connection with the material has been attained, the trouble will entirely disappear. Meanwhile, among the experiments now being tried are the use of wooden packings, contractile clays, stays fastened with lead washers, and so on.

Messrs. Robert Dempster, Ltd., have taken out a patent in which they claim that, with the use of plastic siliceous clay (having a drying contraction of 8 p.ct.) in the joints, the thermal expansion taking place between 200° and 580° C. is gradually absorbed. Similarly, the joints between each segment resting in the stay walls should be made of siliceous clay and the walls built up tight with the retort.

I have inspected a number of settings where silica retorts are in operation, and was especially interested in the experimental settings at Beckton. At these works practically all the carbonizing contractors lay down settings of their own design, incorporating their own ideas for the counteracting of the temporary and permanent expansions. In addition, Mr. Leech and his staff have had a number of experimental settings built also, and in one house alone eight distinct methods of packing have been tried. The information regarding the settings is carefully recorded and discussed at periodical staff meetings. Mr. Leech has kindly provided Fig. 11, Plate 2, which shows the methods now adopted in their all-silica settings. While at the above plant, I inspected a setting built to this standard, which had been used for gas making for three weeks. Careful examination showed that the vertical joints were in substantially the same condition as when built; the wood packings had disappeared and the walls were under weight. (Figs. 12-13).

Gill[13] has given an interesting summary of the practice adopted at the South Metropolitan Gas Company's works; and Harston[14], in his admirable paper, goes into greater detail as to the conditions at Norwich. But in both these cases siliceous and not silica retorts are in use.

It is essential that the temperature be increased very

[13] Gill, *Trans. Cer. Soc.* 22, 377, 1922-1923.

slowly during the heating-up stages, since the faster the "heats" are raised, the greater the permanent expansion. It is interesting to note that the graph on page 18 shows clearly the actual temperatures at which the greatest care is necessary and also that, the harder the fire to which the silica goods have been subjected at the works, the lower the temperatures at which the maximum thermal expansion occurs.

It is my opinion that, if the silica refractories used in the settings conform to the present standard specification for after-expansion, then very little trouble need be expected in horizontal practice; if, however, the combustion chamber temperatures are raised, then a revision

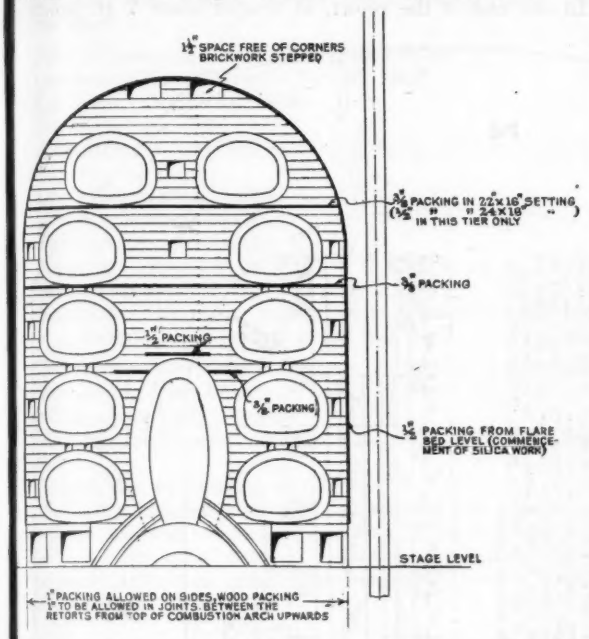
1½" SPACE FREE OF CORNERS BRICKWORK STEPPED
⅜" PACKING IN 22"x16" SETTING (½" " " 24"x16" " IN THIS TIER ONLY)
⅜" PACKING
½" PACKING
⅜" PACKING
½" PACKING FROM FLARE BED LEVEL (COMMENCEMENT OF SILICA WORK)
STAGE LEVEL
1" PACKING ALLOWED ON SIDES, WOOD PACKING TO BE ALLOWED IN JOINTS BETWEEN THE RETORTS FROM TOP OF COMBUSTION ARCH UPWARDS

Fig. 11.—Beckton Standard Setting, showing Allowances for Expansion.

of the specification is necessary, since, as the temperature rises the tendency to expand increases beyond the limits of the specification.

Wear and tear effects due to alternation of temperature, e.g., spalling.—During the war period, considerable losses were experienced in the metallurgical industries through the spalling of silica bricks. It was proved, in the majority of cases, that the defect was primarily due to the fact that the demand was so far in excess of the supply that to a certain extent quality had to be sacrificed for quantity.

Comparing fireclay with silica, there is no doubt that the former is less liable to spall. I know of one silica retort setting, originally built of silica throughout, which, after a short run, had to be let down, so that fireclay mouthpieces could be installed. In practice it is difficult (on account of spalling and cracking) when patching retorts to put into position silica segments, and in many cases siliceous segments are used.

Another interesting case was brought to my notice at the Beckton works, where, within one setting, it was found that, when the retorts were scurfed, a layer of the retort was brought out along with the carbon.

An investigation by the interested parties showed that the porosity of these particular retorts was above the normal. I have enquired from several gas managers who are using silica retorts as to the occurrence of a similar trouble, but in no other case has the defect been observed. Further information was gained as the result of an inspection of silica retorts, which had been let down after a few weeks work. I noted that, midway along the setting and on the third tier, a piece of retort approximately 6 in. by 4 in. by ¾ in. was missing, and I found the fragments in the base near the nostrils. On the opposite side of the chamber I was fortunate enough to locate a similar slab, held in position at one end by the cross-walls. This specimen is on the table for inspection. It is obvious from the ash residue, that the piece must have become detached at an early stage, probably during the heating up. In the same setting, several silica retorts were noticed which exhibited cooling cracks. It has been reported that, in certain silica coke-oven constructions in the U.S.A., the resident engineers were afraid to shut down. On the other hand, I have received a communication from a carbonizing engineer, who has just returned from a visit to the U.S.A. While there, he inspected a number of coke-oven plants running for town gas, but failed to elicit confirmation of the report previously mentioned. Attention is drawn to the data on vertical retorts.

Deterioration when shut down.—While at the Keighley works, I examined a silica setting which had been let down. Mr. Bromley had the interior specially cleared, so that a thorough inspection could be made, and, apart from a small fracture at the junction between the fireclay mouthpiece and the silica, the retorts were in perfect condition.

I am informed that a silica battery at Liverpool has been shut down and re-started three times after the following working days:—

1st	period.	842 days.
2nd	„	188 „
3rd	„	164 „
4th	„	178 „

The settings are still working and the condition is such that they will probably last a further two or three years.

Mr. Morrison reports that he has shut down his composite silica-fireclay retorts without experiencing any trouble. At the Beckton works, where they have had an extended experience with silica retorts, the staff do not report any apparent deterioration when silica settings are shut down.

Lack of Mechanical Strength.—It is generally accepted that the silica refractory is more fragile than fireclay: but while it undoubtedly requires more care in handling, the modern product is quite capable of being transported and handled with ease.

Life under varying conditions not yet established.—I agree that exact data have not yet been published, especially as regards the behaviour of silica in comparatively small units.

It has been said that silica has been exploited only on large plants where suitable apparatus and staff are available to ensure first-class working conditions. Though this may be true, the larger units are carbonizing at higher

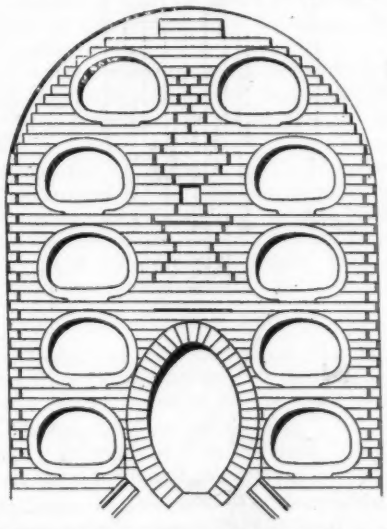

Fig. 12.—Dempster Standard Setting, showing Allowances for Expansion.

temperatures than the smaller works. In any case, the margin of safety, so necessary where supervision is lacking, is much greater with silica than with siliceous or fireclay material. For instance, I have tested the temperature of a vertical installation which should have been working at a maximum of 1320°, and found it to be 1450°. Fluctuations of this magnitude would be very injurious in normal fireclay settings.

Capital Outlay.—This aspect of the question is a very important one, but since the calculations involved are very simple and will vary within wide limits, it is not intended here to include a mass of data which may apply only in isolated instances.

[14] Harston, *Gas Journ.*, **166**, 530, 1924.

VERTICAL RETORTS.

I have visited a number of plants, working under normal conditions and built by —

(*a*) West's Gas Improvement Company.,
(*b*) Woodall, Duckham Company,
(*c*) Drakes Ltd.

In order to obtain further information I inspected one installation of each type, which had been let down and cleaned. Mr. Harris, of Taunton, has furnished particulars relating to his installation, which is a Leeds setting, built by Messrs. Goodall, Clayton & Co., Ltd.

A.—GLOVER WEST.

The Leigh installation consisted of four Glover West bell-bottom retorts (new model). The upper and lower zones were constructed of fireclay bricks, and the central hot zone and combustion chambers of siliceous (88 p.ct.) blocks. Two retorts were cooled and cleaned.

Condition of Refractories.—The fireclay firebricks in the "bell" portion were pitted and abraded; the harder fragments, though standing away from the face, could not be readily detached. The condition of the refractories as a result of the steaming is very similar to the structure of bricks, which have been subjected to the sand blast test. The blocks in the siliceous zone were in very good condition, the surface being free from cracks. I noted that a fair number of the vertical joints were unsatisfactory. In one end of the retort, at a spot some 7 ft. upwards

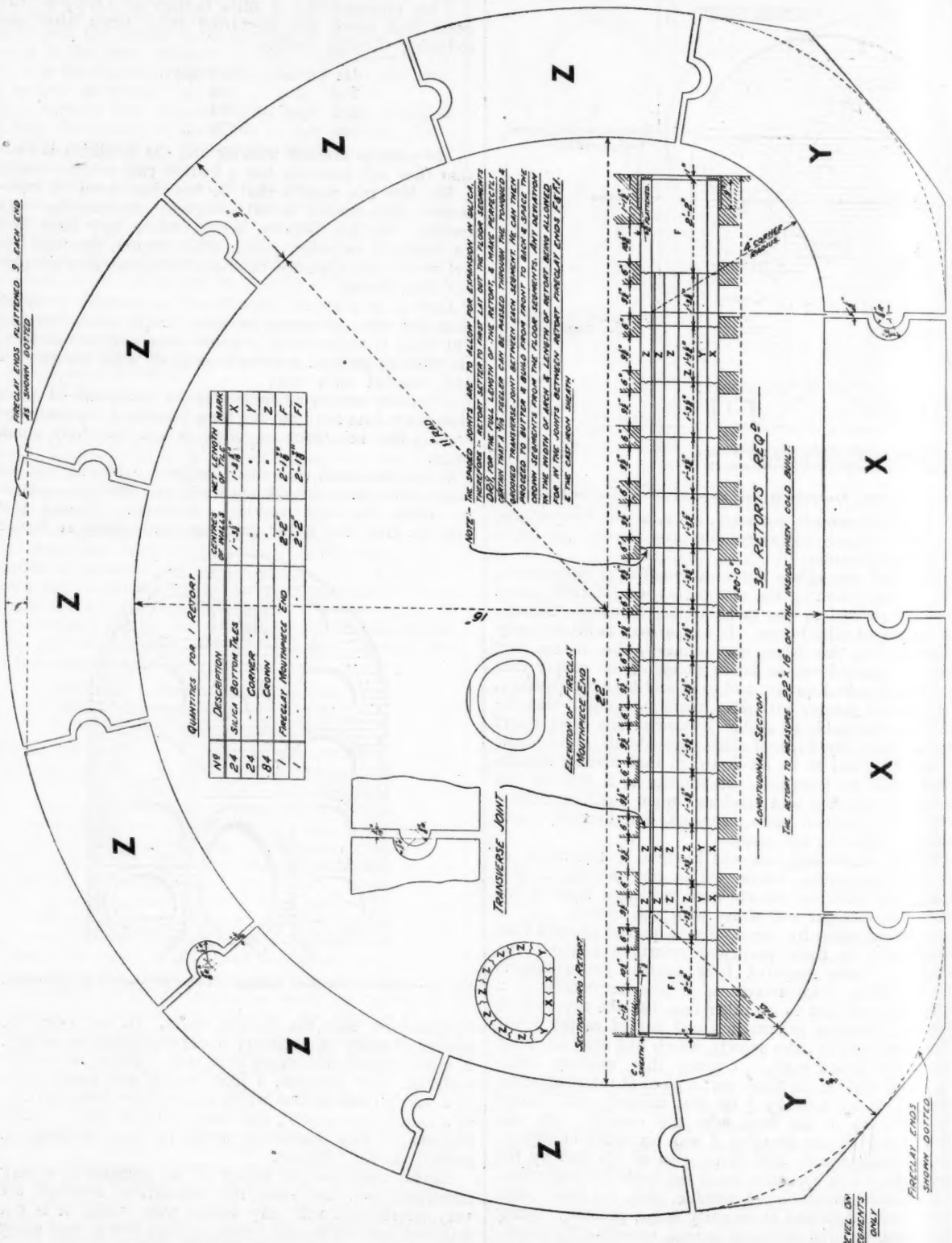
FIRECLAY ENDS FLATTENED 3 FROM END AS SHOWN DOTTED
QUANTITIES FOR 1 RETORT
No | DESCRIPTION | CENTRES OF JOINTS | NET LENGTH OF TILE | MARK
24 | SILICA BOTTOM TILES | 1'-3" | 1'-3" | X
24 | " CORNER " | " | " | Y
84 | " CROWN " | " | " | Z
1 | FIRECLAY MOUTHPIECE END | 2'-2" | 2'-1⅞" | F
1 | " " | 2'-2" | 2'-1⅞" | F1
NOTE - THE SHADED JOINTS ARE TO ALLOW FOR EXPANSION IN SILICA. THEREFORE - RETORT SETTER TO FIRST LAY OUT THE FLOOR SEGMENTS DRY, FOR THE FULL LENGTH OF THE RETORT, & MARK PERFECTLY CENTRE THUS? THE FIELDER CAN BE PASSED THROUGH THE TONGUED & GROOVED TRANSVERSE JOINT BETWEEN EACH SEGMENT. HE CAN THEN PROCEED TO BUTTER & BOND FROM FRONT TO BACK & SPACE THE CROWN SEGMENTS FROM THE FLOOR SEGMENTS. ANY EXPANSION IN THE WIDTH OF ARCH & LENGTH OF RETORT BEING ALLOWED FOR IN THE JOINTS BETWEEN RETORT FIRECLAY ENDS FACE & THE CAST IRON SHEATH
32 RETORTS REQ'D
LONGITUDINAL SECTION
THE RETORT TO MEASURE 22'x 16" ON THE INSIDE WHEN COLD BUILT
ELEVATION OF FIRECLAY MOUTHPIECE END
TRANSVERSE JOINT
SECTION THRU RETORT
A CORNER RADIUS
FIRECLAY ENDS SHOWN DOTTED
BEVEL ON SEGMENTS ONLY

FIG. 13.—DEMPSTER SINGLE RETORT, SHOWING TYPE OF JOINT AND DETAILS OF SETTING.

from the mouthpiece joint, there was a small hole about ½-in. in width, the depth of one block. The fireclay refractories in the upper zones appeared to be quite satisfactory.

The second retort which the author examined was in substantially the same condition as the first as regards the general condition of the refractories, but there was no hole such as that occurring in No. 1 retort. A hole had been drilled in one of the blocks situated in the hottest zone in order to determine to what extent the bricks had been worn. It was found that the block was ⅛ in. thinner than when set into the retort.

Mr. F. Bowen, A.M.I.E.E., the manager at the Leigh Gas-Works, has kindly passed the following data for publication :—

Fuel.—Lancashire seams, 4 feet, and Arley.
Commenced Gas-Making.—Jan. 10, 1922.
Let Down.—March 10, 1924.
Days Worked.—790.
Deductible for Scurfing.—Cleaning mains, furnace repairs, etc., 45 days.
Day's Gas-Making.—745.
Tons Carbonized.—9430.
Tons per Day per Retort.—12·65.
Steaming.—Pressure varied, 5 to 12 lbs. per sq. in.
Mean Pressure.—8 lbs.
Superheat.—None in general, but during specific test periods super-heated steam was used.

No serious deterioration of the refractories. A few small holes, arising from burnt-out joints, led to a slight loss of make near the end of period.

Average combustion chamber temperature in hot zone, 1250° C.

Practically no hanging of charges.

It is my opinion that this installation has done very good service, and I would suggest that the jointing material used is the only feature requiring attention. When the joints have been remade the setting will have a further extended run.

B.—WOODALL-DUCKHAM.

Woodall - Duckham installation at Gas Street works, Bolton. Battery of 7-ton retorts.

Refractories :—

The upper and lower zone, Scottish fireclay bricks.
The medial zone, A6 silica blocks (panelled).
Combustion chambers, A6 silica bricks.

Stated by the designers that their previous experiences led them to introduce new features to accommodate the expansion of the silica refractories.

Several retorts were cooled down and opened for inspection. Retort No. 22 critically examined.

Condition of Refractories.—The fireclay bricks at the top of the retorts were in good condition, with the exception of the four lower courses. The latter exhibited a peculiar crazed appearance, the network of cracks extending into the brick for about ¼ in. The appearance of the upper 18 in. of the silica refractories was interesting, inasmuch as the surface was eroded in several positions, whereas between these patches the condition was very good. In this design of retort there are two bonding or supporting walls on either side, and the disintegration had taken place on the retort face in line with these walls. The depth of the patch was approximately ⅜ in., and starting at the top the width is approximately one foot, gradually decreasing in a tapering direction until at 18 in. the whole surface was sound. Downwards from this point the side walls were in excellent condition, the surface of the bricks was clean and free from cracks, whilst the joints were very firm. The appearance of the end walls in several isolated zones indicated that there had been a slight leakage of combustion gases into the retort through the cavities allowed for expansion. These cavities should theoretically have closed, but they did not do so owing to the total reversible and permanent after-expansion of the silica being less than was anticipated. The silica blocks were sound and the joints firm ; in fact, the whole surface really formed a complete unit.

Erosion extended over a total length of 2 ft. 6 in. in the vicinity of the steam nostrils, the surface being irregularly pitted across the whole section. It was not the extent of the erosion, but rather the peculiar manner in which it occurred, that was noted.

For example, one end of a block would be in good condition, whilst the remaining portion was completely eroded. In others the central portion was eroded and the two ends perfect. The general tendency was for the finer parts to show up in vertical lines with the larger fragments of the refractory standing out in relief.

As distinct from above, the lowest portion of the retort and the large supporting blocks near the end walls were not in so good a condition. The surface was worn away to a fair depth, but the character of the partial disintegration was quite distinct from that previously noted about the steam inlets.

Discussion.—(1) Condition of silica bricks near top of retort.

It is probable that the temperature of the retort face under normal working conditions is such, that any rapid fluctuation which may take place, due to varying moisture content or irregular working of the coal, would bring the silica within the critical temperature range in which considerable reversible expansion and contraction take place for a comparatively small rise and fall in temperature.

At the top of the retort the firebrick masonry is not eroded in the slightest degree ; but it should be remembered that the first course in the silica zone coincides with the uppermost combustion chamber.

The fact that the erosion in the firebrick work was general around the steam nostrils, suggests that there is a close connection between steaming and erosion. The defective surfaces below are probably due to the abrasive action of the descending coke.

The following data were kindly supplied by Mr. W. J. Smith, Gas Engineer and Manager :—

Fuel Used.—Lancashire coking coal.
Moisture Content.—3 to 5 p.ct.
Retort in Use.—Nov. 15, 1921, to Feb. 3, 1924. 5500 tons fuel carbonized during 811 actual working days.
Steaming.—No direct measurements. Tests with waste-heat boiler on an adjacent setting would indicate that about 450 lbs. steam at 550° are admitted per ton of coal carbonized.
Hanging.—Trouble of hanging changes occurred at more or less frequent intervals : thought to depend on (1) quality of coal, (2) speed of throughput, (3) condition of retort (scurfing), (4) heats, (5) degree of steaming.
Scurfing.—Silica retorts appear to grow carbon quicker and require scurfing more frequently than fireclay vertical retorts ; carbon is just as easily burnt off.

Considering the throughput and the general methods of working, involving, as they do, combustion chamber temperatures in the silica zone ranging from 1150° to 1380°, the behaviour of the silica refractories has been abnormally good ; they will doubtless, with a few slight repairs, have a considerable life.

C.—DRAKES, LTD.

Mr. Cartledge, of the Congleton Gas-Works, kindly gave the author permission to visit his plant. It consists of 12 3-ton retorts of which at the time of my visit,

5 were being used for gas making,
4 were " standing by " on low heat,
3 were shut down and cleaned out.

The installation has worked only during the last winter, and the two retorts examined had been gas making for 40 days.

It may seem an unusual procedure to report on two plants after extended runs and then to discuss the condition of one which has been running for a few weeks only. However, my object on this occasion was to ascertain the effect which comparatively rapid cooling has in vertical silica constructions. " A6 " silica blocks were used in the central portion of the setting and combustion arches, Stourbridge fireclay bricks and blocks in the cooler zones at the top and bottom respectively. The silica refractories, apart from a few cracked blocks, were in excellent condition. I was very interested to find that, in the regions near the centre of the silica zones, there were a number of blocks which undoubtedly exhibited cooling cracks, since the

edges of the cracks were quite clean and free from the usual dark coloration present in older fractures.

Fireclay.—The fireclay refractories were showing signs of erosion, the appearance (not the extent) being similar to that described in the note on the Bolton plant. The appearance of one block was very unusual. During the firing in the oven a portion of the surface had been slogged, either from impurities in clay or from ash in the fuel. This denser portion was standing out in relief while the surrounding parts were eroded away. This suggests that texture and density play an important part in the resistance to erosion.

Mr. Cartledge stated that the temperature in the various zones of the setting ranged from 1050° to 1380°. My own pyrometric readings confirmed this information. No figures were available as to the extent of the steaming.

DESSAU VERTICAL RETORT.

The installation at Taunton is an adaptation of the Dessau intermittent retort. Silica bricks "A3" were used in the chamber and cross walls. The retorts, which are 3 ft. 3 in. by 10 in. at the top, 4 ft. by 17 in. at the bottom, and 14 ft. in length, are buil tof the same silica material.

Fuel carbonized.—Somerset smalls.
Weight of charge.—17 cwt.
Carbonizing period.—12 hours.
Worked for 370 days.
Present condition very good.

Mr. Harris states that the introduction of silica has enabled him to speed-up the rate of carbonization considerably.

CHAMBER OVEN.

The following data concerning town-gas chamber-oven practice have been supplied by Messrs. Koppers. The information has been included because it is quite likely that similar carbonizing methods may be tested out in Great Britain in large installations.

1.—*Oven Dimensions :*—Height, 10 ft. 10 in., length, 23 ft. 8½ in., width, 13½ in. The dimensions for the largest ovens are :—Height, 12 ft. 6 in, length, 20 ft. 8 in., width, 16ft. A narrow oven of slightly smaller capacity has the following dimensions :—Height, 12 ft., length, 42 ft. 2½ in., width, 14 ft.

2.—*Moisture in Coal :*—The coals used in the coke plants contain, on an average, from 3 to 5 p.ct.. moisture, but run as high as 12 p.ct. when washed coal is used.

3.—*Chlorine in Coal :*—As chlorine has no marked destructive action on silica bricks, the coals are not generally analyzed for chlorine. The chlorine content, where it has been determined, is very low in American coals. In coals mined close to the seashore, in Nova Scotia, the chlorine content was found to be 0·05 p.ct. This is high compared with the usual American coals.

4.—*Size of Coal :*—At some plants the coal is crushed in a Bradford breaker, to 1¼-in. size, and then charged to the ovens. In other plants the 1¼ in size is pulverized so that 80 p.ct. passes through ⅜-in. aperture. Pulverization is always applied when different kinds of coal are being mixed.

5.—*English Tons per Charge :*—The ovens mentioned in paragraph 1 have a capacity of 6·14 and 13·5 tons respectively (1 ton = 2240 lbs.).

6.—*Method of Charging :*—No stamping is being used. The coal is always charged from a larry car, through holes in the top of the oven chamber.

7.—*Free Space Above Charge in Oven :*—Approximately 10 in.

8.—*Distribution of Temperature on Flue Side—Top to Bottom :*—1320° at top ; 1395° at bottom.

This temperature is regulated to suit the particular kind of coal which is being carbonized.

9.—*Time of Carbonization :*—A good average figure is 12 hours coking time for a 14-in. Becker oven. One of the installations of 14-in. Becker ovens is running continually on 11 hour 5 minute net coking time with a flue temperature of 1350° C. We have no comparative figures in regard to coking time in fireclay or semi-silica ovens, as that type of construction has been entirely abandoned over here. Only silica ovens are now being constructed, and all ovens now being built in the States are of the Becker Type.

10.—*Corrosion :*—None.

11.—*Temperature of Charge at Conclusion of Carbonization :* 980°—1040°C.

12.—*Analysis of Gas :*—The analysis of the gas varies greatly according to the kind of coal used. The following may be considered representative.

N_2	H_2	C_2	CO	CO_2	CH_4	C_2H_4	C_6H_6
6·0	47·3	0·3	6·8	2·2	33·9	2·4	1·1

Volume p.ct.

13.—*Life of Oven :*—Some of our plants have been in continuous operation for 15 years without any repairs to the brickwork, and are still running. We are therefore not in a position to tell the life of silica ovens. One plant has to date carbonized 100,000 tons per oven, and is still in first-class condition.

APPENDIX.

NOTES ON MICRO-STRUCTURE OF RETORTS DESCRIBED IN THE FOREGOING PAPER.

By A. SCOTT, D.Sc., M.A.

Micro-structure of used and unused Refractories :—Several of the materials described in this paper have been sectioned, and brief notes on the micro-structure, both of the used and unused retorts are given below :—

A2N.—This material is composed of fragments of rock in a dark fine-grained matrix, which contains isolated crystals of quartz. Only the minute crystals have undergone conversion, all the coarser material still being in the low-temperature form, except round the margins where there is a peripheral development of crystobalite. The total amount of conversion is about 30 to 40 p.ct., but the converted material is so finely ground as to make it impossible to ascertain its exact nature ; much of it seems to be crystobalite. Some of the coarser rock fragments are highly converted, and seem to be of the nature of prefired grog.

A3.—This material consists of sharp fragments of a fine-grained ganister-like rock in a matrix which has undergone a fairly high degree of conversion. The grain-size of the quartz crystals in the rock fragments is comparatively small, for partial conversion to crystobalite has occurred round the margins of each crystal where the proportion of quartz is low. This mineral forms a large proportion of the matrix. However, here and there areas occur composed apparently of a mineral with considerable double refraction, and resembling the calcium silicate wollastonite. The proportion of unconverted quartz is of the order of 35 to 40 p.ct.

A6.—In this material the rock fragments are much more altered than in either of the preceding cases, and contain appreciable amounts of crystobalite. The matrix consists of a dark semi-opaque glass containing an abundance of minute crystals of crystobalite, no tridymite being present in the section. The proportion of quartz in the material, as a whole, is of the order of 15 to 20 p.ct.

A7N.—This material consists of angular fragments set in a double refracting matrix. The rock fragments show practically no trace of residual quartz, but are entirely composed of crystobalite except round the margins where, occasionally, crystals of tridymite can be detected. The matrix contains a certain amount of clear material, but is apparently mainly tridymite. The brick, as a whole, has undergone a high amount of conversion to the high-temperature forms of silica, and seems to have been very well fired. The amount of unchanged quartz in negligibly low.

B3.—This material consists of minute sub-angular grains of quartz in a dark matrix in which it is difficult to distinguish anything. The quartz grains themselves have undergone a partial change around the margin, but the proportion of this mineral is still fairly high and approximates to 60 p.ct.

BI2C.—This is a piece of the siliceous material from the combustion chamber of a retort-setting. Several very definite layers can be distinguished under the microscope. On the outside there is a black, apparently opaque layer about 1 mm. thick and containing comparatively few pore spaces. There is then a layer of black material with comparatively large pores, this layer being not quite so opaque as the margin, and having a thickness of approximately 3 mm. Next is a wider layer about 2 to 3 mm. in

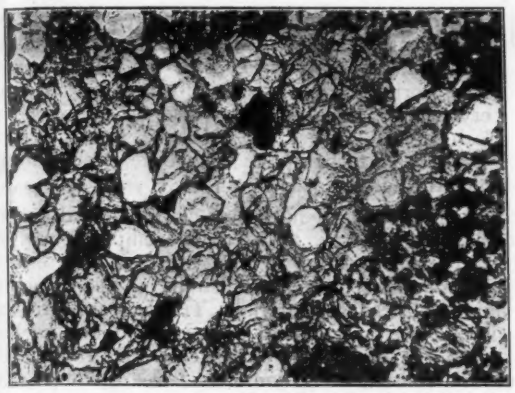

Fig. 14.—Micro-section of Retort A2 showing isolated quartz grains in a converted matrix.

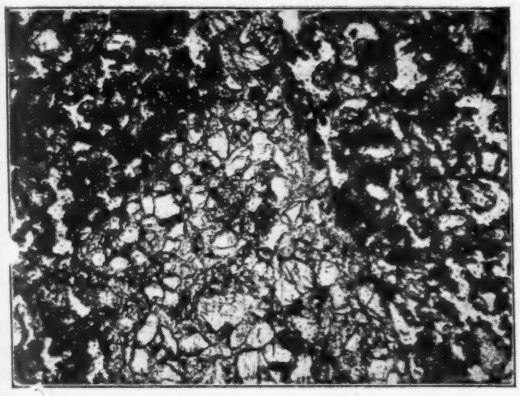

Fig. 15.—Micro-section of A3 showing regular fragments containing quartz and set in a dark ground mass.

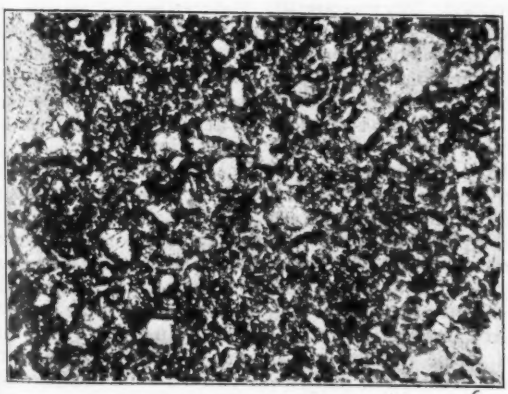

Fig. 16.—Micro-section of A6 showing higher degree of conversion than above figures.

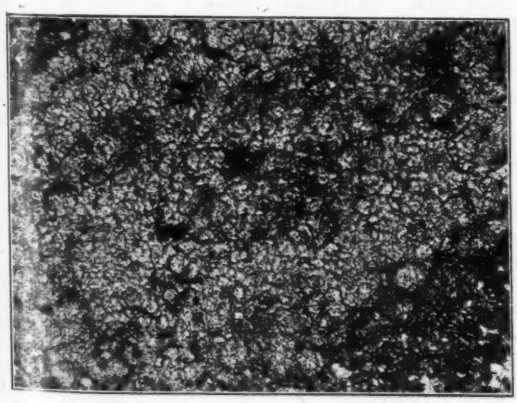

Fig. 17.—Micro-section of A7. No trace of quartz can be distinguished, the mass of the material being crystobalite.

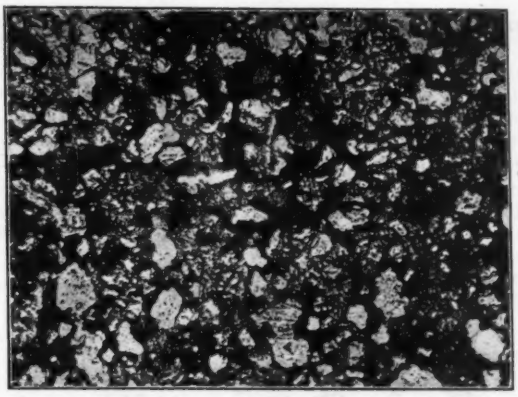

Fig. 18.—Micro-section of B3 showing clear quartz grains in a matrix which is partly opaque material and partly crystobalite.

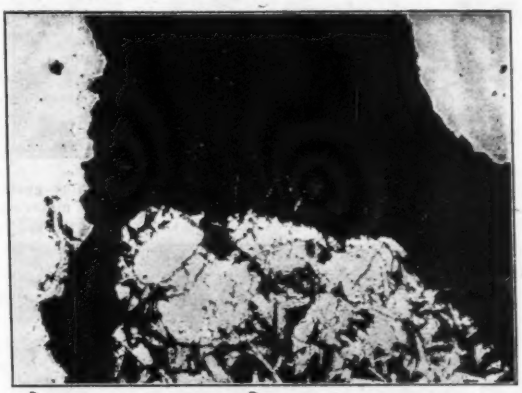

Fig. 19.—Photograph of dark margins of A12 showing needles of sillimanite in the opaque glass together with tridymite in the light area.

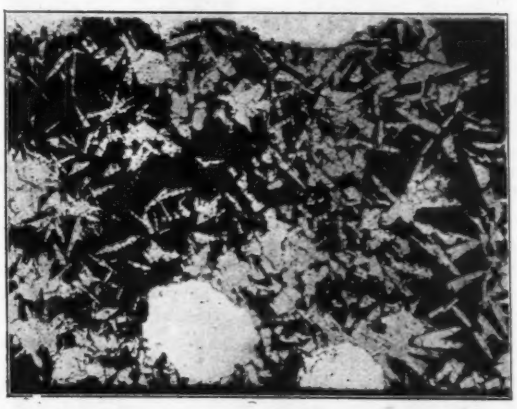

Fig. 20.—Photograph of A12 showing numerous wedge-shaped crystals of tridymite in the area next to the dark band.

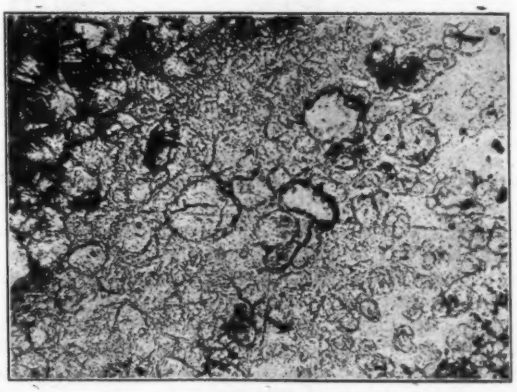

Fig. 21.—Glassy area in Retort No. A12 mainly composed of minute crystobalite.

thickness which appears to be a clear glass except where it is in contact with the black along its margin. The white layer seems more opaque and contains numerous small white fragments. Beyond the white layer is a reddish layer forming the main mass of the brick.

Under the microscope, the dense black area is seen to consist of a dark opaque glass, the opacity of which varies in different parts of the section. In this glass can be distinguished numerous cuboidal and octagonal fragments of a black opaque mineral which seems to be a

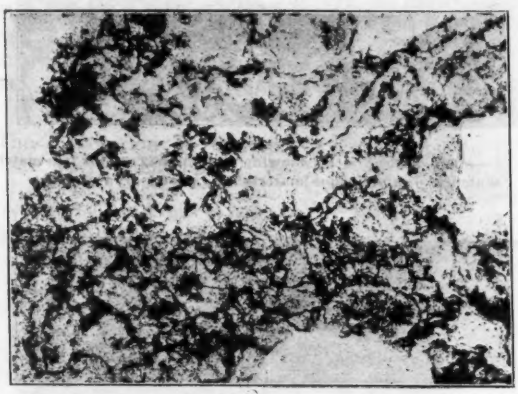

Fig. 22.—Main portion of used Retort A12 consisting of fine-grained tridymite in a dark matrix which is diminished by foreign material.

Fig. 23.—Photograph of Retort AIC showing development of coarse tridymite in a material which is completely converted, no trace of quartz grains being visible.

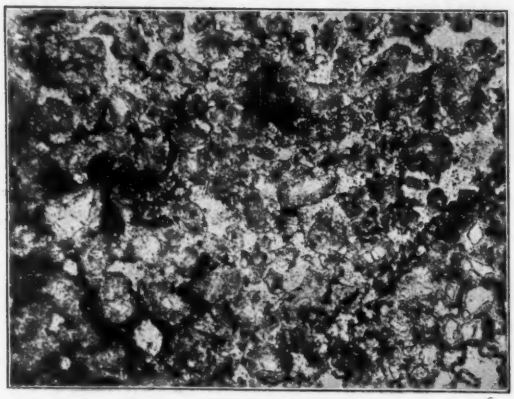

Fig. 24.—AIR. Conversion in this case has been partial and a core of quartz can be detected in each grain, the margin of the grain being crystobalite.

spinel, the crystals of which are surrounded by an area of clear glass. It is probable that the opacity of the rest of the material is due to the presence of minute crystallites of spinel material.

The opacity of natural glasses is often similarly explained by the presence of innumerable minute crystallites in a clear glass. The porous area, under the microscope, consists of two types of material:

(1) A similar glass which also contains elongated crystals which seem to be sillimanite.

(2) The other portion of this dark area is itself composed entirely of well-shaped crystals of tridymite in a blackish matrix. It is of the same nature as the portion already described. The tridymite crystals are large, and show the typical wedge and lath-shaped appearance. Black, spinel crystals, which seem to be mainly magnetite, occur throughout this area.

Occasionally, large fragments of clear material occur in the dark area, and this seems to be composed partly of crystobalite and partly of tridymite. They seem to represent fragments of rock which have undergone conversion in the use of the material. The dark area gradually fades into the clear material already described as being adjacent to it. The margin of this clear material is highly porous, and consists of tridymite in a clear glass; but the main mass of the white area seems to be composed of very minute crystals of tridymite containing local areas of crystobalite. The latter probably represents recently converted quartz grains. The amount of foreign material in this part of the brick is comparatively slight. Interspersed amongst the tridymite can be seen numerous minute crystals which are probably crystobalite. A partial analysis of this material has been made and the composition is as follows:

SiO_2	88·64
TiO_2	0·62
Al_2O_3	8·06
Fe_2O_3	0·68
CaO	0·76

From this composition it might be expected that the material consists of a form of silica together with a certain amount of sillimanite, and this is what is actually found. The major portion of the brick consists of a fine ground aggregation of tridymite with numerous areas of crystobalite, the whole forming a fine-grained mass in which the original rock fragments can still be distinguished, and into which occasionally foreign material seems to have penetrated. Microscopically, this part is sharply delineated from the clear area above mentioned. The crystobalite here undoubtedly represents converted fragments of rock, while numerous isolated grains which have likewise recently undergone a change can also be seen. No trace, however, of residual quartz is found even at a distance of more than 4 mm. from the black edge.

AIR.—This material is a piece taken from the inside of a retort which had been in use for about 2000 days. It is difficult to distinguish the original rock fragments, and the sample now shows rounded crystals of quartz set in a dark matrix. The quartz crystals are surrounded by a layer of a material which seems to be composed of crystobalite, and which undoubtedly represents the transformed margins of the original quartz. The matrix seems to be mainly crystobalite, although a number of minute crystals of tridymite can also be distinguished. An amount of black opaque material has penetrated the ground mass between the quartz grains, but the latter are quite unaffected by it. The proportion of residual quartz is small and probably equal to about 8 to 12 p.ct.

AIC.—This is a piece of the same material taken from the combustion side of the retort, after having been in use for a similar period. In this case, the quartz has entirely disappeared, and it is impossible even to delineate the original rock fragments. The material consists mainly of large, well-developed crystals of tridymite together with rounded grains with very low double refraction. Locally, in the isotropic ground mass, which seems to consist of glass, wedge-shaped twins of tridymite are frequent. The rounded grains with the low double refraction are apparently composed of minute crystals of crystobalite, and represent quartz crystals which have undergone conversion during the use of the material in the setting. Similarly the coarse aggregates of tridymite throughout the piece are due to the transformation of the matrix from crystobalite to its present form.

After giving a summary of the paper, Mr. Emery described a number of samples which he had brought to the meeting.

REPORT OF REFRACTORY MATERIALS JOINT RESEARCH COMMITTEE.

INTRODUCTION.

The Committee are glad to be able to present further communications recording work done by the British Refractories Research Association,* which is of interest to the gas industry. Much more research is still needed to produce results in the form of goods capable of enduring the high temperatures towards which practice is tending. The Association appears, however, now to be getting into more effective work.

The communication by Mr. A. J. Dale on the relation between composition and refractoriness under load represents a large amount of work, although the research is still incomplete. The same remark applies to the work of Mr. S. R. Hind on the purification of fireclays, which, though not immediately bringing about any striking advance, should prepare the way for improvements in the methods of manufacturers for dealing with the clays at their disposal.

The work of Messrs. Hugill and Rees on the effect of repeated burning of lime-bonded silica bricks shows that prolonged "soaking" of the bricks in the kiln increases their strength by completing changes in the allotropic form of the silica which should not be left to occur in the gas-works furnaces. We are promised a further communication on this subject. Tests on silica bricks which have been kept in stock emphasize the necessity of care in the storage of bricks of this class, which suffer considerably by exposure to weather.

Dr. Mellor contributes the first portion of a paper on the causes of variation in the sizes of refractories, a subject which is of particular importance where bricks and blocks are used to form gas-tight joints in retorts and regenerators.

While for some purposes—*e.g.*, the walls of retorts and the interior of regenerators—a higher-conductivity material is desired, there has of recent years been an increasing demand for a heat-resisting material of low thermal conductivity to reduce the loss of heat from the settings. This is especially emphasized where a use for the surplus heat is being found by waste-heat boilers. In this connection, there are communications by Mr. A. T. Green, representing a large amount of work, on the conditions affecting the thermal conductivity of firebrick. This was one of the directions in which the Institution requested that research should be conducted.

It is hoped that the publication of these and other reports of research will assist British manufacturers to meet the demands of the gas industry for improved material.

(*A*) NOTE ON THE STORAGE OF SILICA REFRACTORIES.†

W. J. REES, B.Sc.Tech., F.I.C.

Care is usually exercised in the storage of bricks or other refractory goods made from silica. Cases of considerable alteration in the physical behaviour (particularly the mechanical strength and spalling tendency) of silica bricks which have been stored under unsuitable conditions have occasionally come under my notice. For instance, a batch of silica bricks which had been stored in the open for six months (October to April) spalled badly in use, while normal freshly delivered bricks of the same make, and having the same texture, specific gravity, etc., were satisfactory. The good bricks had a cold crushing strength of 3000 lbs. per sq. inch, while that of the stored bricks was only 2200 lbs. per sq. inch. The bricks in both tests were dry and were placed on end in the testing machine, the ends being previously made plane and parallel.

Observations have been made on two batches of commercial silica bricks, one of coarse texture and the other of moderately fine texture. The fresh bricks had the following chemical composition and physical properties:

	Coarse textured brick.	Fine texturedbrick.
Silica	95·34%	94·90%
Alumina	1·02	1·34
Iron oxide	0·79	0·88
Titanium oxide	0·21	0·31
Lime	1·91	1·84
Magnesia	0·18	0·16
Alkalies (as K_2O)	0·46	0·51
	99·91	99·94
Apparent density	1·76	1·79
True density	2·45	2·38
Porosity	29%	25%
Refractoriness	Cone 33	Cone 32
Average of 3 Tests — Cold crushing strength	2400 lbs. per sq. in.	2900 lbs. per sq. in.

Twelve bricks of each batch were then placed in the open, unprotected from the weather, for the months February to May. (Snow in the early part of this period and frequent rainy and windy days.) Bricks from each batch were also stored under approximately the same temperature conditions, but protected from the weather, and a further batch was placed in a warmed store-room.

The mechanical strength of these batches of bricks at the end of the four months was:

	Coarse texture lbs.	Fine texture per sq. in.
Unprotected from weather (average of 3 bricks)	1400	2150
Protected " " " " "	2100	2600
Kept in store-room " " "	2350	2900

The bricks were air-dried before testing.

The fine-textured bricks stored in the open showed no external signs of deterioration, but on several of the coarse-textured bricks there was slight surface crumbling. Examination of fractures showed fine cracks or crizzles in the matrix, particularly in the coarse-textured bricks. Rough spalling tests were made by alternately slowly heating the bricks to 1350° C.; upon subsequently placing them on a cold iron plate, a much increased spalling tendency in the unprotected bricks was indicated. Chemical analyses of the stored bricks indicated no appreciable change in chemical composition in any of the batches. These observations emphasize the importance of adequately protecting silica bricks during storage. In order further to investigate this loss of strength, a number of briquettes were made from selected Totley ganister bonded with 2 per cent. of lime. The grading of the batches was as follows: *A* giving coarse-textured and *B* fine-textured briquettes.

	A	B
Passing 5 mesh but retained on 10 mesh	20%	10% by weight
" 10 " " " " 20 "	17%	17% " "
" 20 " " " " 90 "	20%	20% " "
" 90 " " " " 120 "	25%	20% " "
Through 120 mesh	18%	33% " "

The average chemical analysis of the burned briquettes was:—

Silica	95·71%
Alumina	0·84
Iron Oxide	0·51
Titanium Oxide	0·22
Lime	2·04
Magnesia	0·16
Alkalies (as K_2O)	0·41
	99·89

The approximate size of the burned briquettes was 120 mm. × 28 mm. × 15 mm., and the weight 90 grammes. Batches of the briquettes were burned in a gas-fired labora-

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* These communications which follow are published with the permission of the Committee of the Privy Council for Scientific and Industrial Research. They comprise:
(*a*) Note on the Storage of Silica Refractories, by Mr. W. J. Rees, B.Sc.Tech., F.I.C.
(*b*) The Relation between Ordinary Refractoriness, Under-load Refractoriness, and Composition, Physical and Chemical, of Refractory Material, Part I., by Mr. A. J. Dale.
(*c*) Note on Refractoriness under Load, by Dr. J. W. Mellor.
(*d*) Sedimentation as a Means of Purifying Clay, by Mr. S. R. Hind, B.Sc.
(*e*) The Effect of Repeated Burning on the Structure and Properties of Lime-bonded Silica Bricks, Part I, by Mr. W. Hugill, B.Met., and Mr. W. J. Rees, B.Sc., F.I.C.
(*f*) Some Causes in the Variation of the Sizes of Refractories—Bricks and Blocks, Part I., by Dr. J. W. Mellor.
(*g*) The Thermal Conductivity and some other Properties of two Commercial Heat-insulating Bricks used in Kiln Construction, by Mr. A. T. Green.
(*h*) The Influence of Texture on the Transmission of Heat through Fire-bricks, by Mr. A. T. Green.

† Bulletin 2, p.8 B.R.R.A., Jan., 1923.

tory furnace at 1300° C., 1400° C., and 1500° C. Briquettes of each grade and each burning were then treated

(*a*) By boiling in distilled water for six hours, the water being then evaporated to dryness in a platinum basin and the residue weighed and analyzed. (Blank boilings, etc., were conducted in similar vessels as a check.)

(*b*) By soaking for one week in cold distilled water; the water being then evaporated and the residue weighed and analyzed.

(*c*) By supporting horizontally (the supports being under the extreme ends of the briquettes) in a glass vessel with free circulation of air, but protected from dust, and spraying to saturation with distilled water twice daily for forty days. The drainage from the briquettes was evaporated, weighed and analyzed.

(*d*) The mechanical strength of the treated and untreated briquettes was compared by compression on edge in a Brinell machine.

The following are the results of these tests:

A.—Coarse-texture briquettes burned at 1300° C.

Powder density 2·49. Cold-crushing strength 600 lbs. per sq. inch.

Treatment	Wt. in grammes o dissolved material.				Cold-crushing str. in lbs. per sq. in.
	Total	CaO	Alkalies	Al_2O_3	
Boiled *a* ..	·025	·018	·004	·003	500
Soaked *b* ..	·024	·016	·004	·004	500
Sprayed *c* ..	·018	·012	·003	·003	400

B.—Fine texture briquettes burned at 1300° C.

Powder density 2·48. Cold-crushing strength 650 lbs. per sq. inch.

Treatment	Wt. in grammes of dissolved material.				Cold-crushing str. in lbs. per sq. in.
	Total	CaO	Alkalies	Al_2O_3	
Boiled *a* ..	·033	·022	·004	·006	500
Soaked *b* ..	·029	·022	·002	·005	500
Sprayed *c* ..	·022	·016	·002	·004	450

A.—Briquettes burned at 1400° C.

Powder density 2·42. Cold-crushing strength 650 lbs. per sq. inch.

Treatment	Wt. in grammes of dissolved material.				Cold-crushing str. in lbs. per sq. in.
	Total	CaO	Alkalies	Al_2O_3	
Boiled *a* ..	·021	·009	·005	·006	500
Soaked *b* ..	·012	·006	·002	·004	480
Sprayed *c* ..	·012	·007	·002	·003	450

B.—Briquettes burned at 1400° C.

Powder density 2·41. Cold crushing strength 700 lbs. per sq. inch.

Treatment	Wt. in grammes of dissolved material.				Cold-crushing str. in lbs. per sq. in.
	Total	CaO	Alkalies	Al_2O_3	
Boiled *a* ..	·025	·012	·006	·007	550
Soaked *b* ..	·016	·009	·002	·005	550
Sprayed *c* ..	·010	·005	·002	·003	450

A.—Briquettes burned at 1500° C.

Powder density 2·35. Cold-crushing strength 700 lbs. per sq. inch.

Treatment	Wt. in grammes of dissolved material				Cold-crushing str. in lbs. per sq. in.
	Total	CaO	Alkalies	Al_2O_3	
Boiled *a* ..	·009	·005	·002	·002	600
Soaked *b* ..	·007	·005	nil	·002	650
Sprayed *c* ..	·007	·005	nil	·002	550

B.—Briquettes burned at 1500°C.

Powder density 2·33. Cold-crushing strength 750 lbs. per sq. inch.

Treatment	Wt. in grammes of dissolved material.				Cold-crushing str. in lbs. per sq. in.
	Total	CaO	Alkalies	Al_2O_3	
Boiled *a* ..	·011	·007	·002	·002	600
Soaked *b* ..	·008	·005	nil	·003	600
Sprayed *c* ..	·005	·004	nil	·001	550

The separation of the dissolved material into CaO, alkalies and Al_2O_3 is approximate; the Al_2O_3 contains a little silica and iron oxide.

There are definite indications that the loss in strength of silica bricks exposed to weather is in part due to a slight degradation of the bond by hydration and solution in water, as well as to the physical effect of frequent wetting and drying.

In these tests there is little or no distinction in the behaviour of the coarse and fine textured briquettes, but in both cases the briquettes burned at higher temperatures were more resistant to the water attack. The loss in strength was in all cases more marked with the long exposure to moisture in test *c*. This test is an approximation to the storing of bricks, without protection, in the open, and further emphasizes the need for suitable protection of silica bricks during storage.

I am indebted to Mr. P. M. Robinson, M.Met., for assistance in carrying out the experimental work and making observations.

Department of Refractory Materials,
University of Sheffield. *November*, 1923.

(*B*) THE RELATION BETWEEN ORDINARY REFRACTORINESS, UNDER-LOAD REFRACTORINESS, AND COMPOSITION, PHYSICAL AND CHEMICAL, OF REFRACTORY MATERIAL.—PART I.

A. J. DALE.

INTRODUCTION.

The influence of load on the softening point of refractories has been the subject of a considerable number of papers, among which may be mentioned the reports of Mellor and Moore[1], Mellor and Emery[2], and Emery and Bradshaw[3].

The first-named authors devised the method at present in use in this country for testing refractory material under load, and arrived at sundry conclusions regarding the behaviour of fireclay and silica materials. A consideration of the classified results,† showing analyses, ordinary refractoriness, and under-load refractoriness of 62 commercial products, while not leading to any rigid generalization,

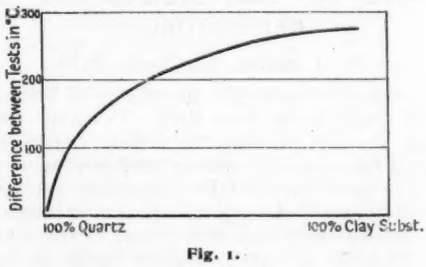


Fig. 1.

affords confirmation of the conclusions previously reached by Mellor and Moore, and later by Emery and Bradshaw, that, generally speaking, the more aluminous the refractory, the greater the difference between the normal softening point and the breakdown point under load at high temperatures.

The following tabulation is arranged in descending order of silica content. An unsuccessful attempt was made to correlate the SiO_2, Al_2O_3, and total fluxes by means of a triangular diagram.

* Bulletin 5, p. 21, B.R.R.A., Dec., 1923.

† I am indebted to Dr. J. W. Mellor for these data. Regarding the results of the under-load refractory test, Dr. Mellor states that in these tests, no distinction had been made between a break-down by softening and a break-down by rupture, nor is any account taken of the variations in grain size and proportions of grog, methods of manufacture, etc.

Number	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	K_2O	Na_2O	Loss	Total	Clay	Fels.	Qrtz.	Ferric Oxide	Lime	Ordi'ary Refract.	Under load	Diff.	Remarks.
1	96·67	0·36	0·68	0·50	0·01	1·27	0·08	0·48	0·04	100·09	0·18	3·36	94·85	0·50	1·27	Cones 32-33	29	Cones 3-4	After Expansion 0·15%
2	95·73	Trace	0·66	0·31	0·06	1·96	0·50	1·12	0·06	100·40	nil	9·58	88·16	0·29	1·97	35	29	6	After Expansion 0·15%
3	95·56	—	1·28	0·55	0·02	1·66	0·12	0·74	0·26	100·19	0·87	5·13	91·34	1·27	1·65	33-34	27	6-7	
4	95·42	0·24	0·83	0·65	0·02	2·45	0·60	0·20	0·02	100·43	nil	4·8	92·5	0·65	2·45	32-33	26	6-7	After Expansion 0·06%
5	95·41	0·56	0·81	1·25	—	1·78	0·20	0·26	0·10	100·37	0·9	2·8	93·3	1·25	1·78	32-33	30-31	2	After Expansion 0·12%
6	95·26	nil	0·87	0·45	0·17	2·26	0·70	0·60	0·04	100·35	nil	7·7	89·6	0·4	2·2	33	32	1	After Expansion cone 12, 2 hrs., 0·015%
7	94·90	nil	0·68	0·35	0·20	2·19	0·77	0·42	0·18	99·69	nil	7·14	90·26	0·35	2·19	32	29	3	After Expansion cone 12, 2 hrs., 0·11%
8	94·57	0·43	1·79	0·81	0·12	1·64	0·26	0·30	0·19	100·11	3·0	3·3	91·6	0·8	1·6	32-33	27	5-6	
9	94·48	0·1	1·41	0·53	0·46	2·38	0·70	0·40	0·12	100·48	0·6	6·6	89·9	0·5	2·4	31	30	1	No change. Cone 12, 2 hrs.
10	93·2	0·15	1·07	0·78	0·10	3·80	0·30	0·12	0·10	99·62	1·55	2·5	91·0	0·7	3·8	32-33	31	1-2	After Expansion 0·12%
11	92·90	nil	2·37	1·50	0·16	1·28	1·10	0·68	0·04	100·03	1·12	10·68	88·44	1·50	1·28	33-34	15	13-14	
12	91·95	1·54	1·96	0·63	0·23	3·04	0·58	0·58	0·08	99·59	1·8	7·0	87·1	0·6	3·0	32	20	7	
13	91·82	nil	3·44	0·94	0·05	2·51	0·66	0·50	0·15	100·07	5·4	6·9	83·9	0·9	2·5	33-34	18	10-11	
14	88·98	0·60	7·59	0·72	0·13	0·88	0·58	0·46	nil	99·94	15·9	6·2	76·3	0·7	0·9	34	14	15	After Expansion 0·53%
15	84·10	0·83	11·78	1·95	0·11	0·34	0·28	0·70	0·14	100·23	25·8	5·7	66·4	1·9	0·3	26-27	14	7-8	
16	83·27	1·21	11·23	0·87	0·39	0·77	1·04	0·42	0·32	99·52	23·67	8·58	66·26	0·85	0·75	26	16	5	After Expansion Cone 14, 2 hrs., 0·09%
17	82·98	0·72	12·3	2·5	0·28	0·26	0·82	0·46	0·14	100·46	26·5	7·3	63·7	2·3	0·2	20-26	13-14	7	
18	81·16	1·04	14·80	0·81	0·08	0·80	1·00	0·60	nil	100·27	31·2	9·2	58·0	0·77	0·76	30	18-19	6-7	After Expansion 0·135%
19	79·36	1·52	15·35	1·75	0·14	0·98	0·74	0·56	gain 0·07	100·4	33·17	7·42	56·89	1·66	0·93	28	16	7	After Contraction 0·02%
20	79·36	0·63	16·05	2·19	0·27	0·21	0·98	0·22	0·20	100·11	26·7	7·2	58·4	2·19	0·21	30	14	11	After Expansion 0·09%
21	78·90	0·71	16·14	1·87	0·13	1·02	0·88	0·46	0·20	100·31	34·9	7·6	54·6	1·8	0·9	29	17-18	6-7	After Expansion Cone 12, 2 hrs., 0·26%
22	77·75	1·04	18·32	1·25	0·14	0·29	1·00	0·50	0·20	100·49	39·38	8·48	50·68	1·18	0·28	30	19	6	After Contraction 0·25%
23	77·10	1·32	18·59	1·66	0·25	0·30	0·46	0·42	0·16	100·26	44·1	5·28	54·54	1·66	0·3	29	14-15	9-10	
24	75·76	0·99	18·91	1·75	0·04	0·80	1·12	0·36	0·38	100·11	40·9	8·4	48·2	1·7	0·8	31-32	15-16	11	
25	74·69	0·62	21·37	1·01	0·17	0·41	1·14	0·58	0·18	100·17	45·63	9·64	43·24	0·94	0·41	30	19	6	After Contraction 0·075%
26	74·03	0·63	23·17	0·93	0·01	0·01	0·51	0·41	0·01	99·68	51·73	5·08	42·41	0·86		31	19	7	After Contraction 0·17%
27	73·60	1·11	20·55	1·88	0·36	0·24	1·16	0·42	0·20	99·52	45·1	8·1	44·8	1·8	0·2	28	17	6	
28	73·14	1·16	22·9	1·51	0·05	0·29	0·64	0·34	0·19	100·22	50·75	5·46	42·1	1·4	0·3	32-33	15-16	12	After Contraction nil.
29	71·03	1·00	23·99	1·64	0·06	0·49	0·96	0·32	0·19	99·78	52·2	7·1	38·9	1·5	0·5	31	18	8	After Contraction 0·26%
30	70·23	1·19	23·77	2·56	0·30	0·22	1·16	0·42	0·20	100·05	55·3	9·5	39·8	2·6	0·2	26-27	14-15	7	After Contraction 0.07%
31	68·86	1·46	24·92	2·66	0·38	0·60	0·86	0·48	0·22	100·44	54·3	7·3	35·2	2·5	0·6	30	14	11	No change. Cone 12, 2 hrs.
32	66·86	1·25	26·65	2·69	0·28	0·28	0·18	0·40	0·16	99·75	62·3	9·5	33·3	2·69	0·28	29	16	8	After Contraction 0·72%
33	65·20	1·51	29·54	0·75	—	0·37	0·94	1·74	0·25	100·30	60·89	14·70	23·35	0·33	0·68	32	14	13	After Contraction 0·72%
34	63·56	1·56	29·92	2·25	0·25	0·55	1·02	0·59	0·24	99·94	64·42	8·83	24·17	2·05	0·50	29-30	13-14	11	
35	62·62	1·33	27·44	3·59	0·21	0·33	3·52	0·76	0·39	100·19	52·65	23·91	19·78	3·34	0·30	29-30	16	8-9	After Contraction 1·62%
36	61·76	1·66	31·43	1·51	trace	1·18	0·62	1·62	0·44	100·22	65·94	11·86	19·38	1·37	1·07	30	14	11	After Contraction 0·30%
37	61·55	1·47	29·26	2·81	0·12	1·00	1·64	1·20	1·34	100·39	60·09	15·76	20·17	2·62	0·92	19	11-12	7-8	
38	61·26	1·35	31·63	1·56	0·25	0·92	1·84	0·94	0·30	100·05	65·3	15·2	17·2	1·4	0·9	30-31	14-15	11	
39	61·22	1·72	32·81	1·81	—	0·63	0·66	0·32	0·43	99·60	71·96	5·33	20·49	1·70	0·60	31-32	16	10-11	After Contraction nil.
40	59·90	2·27	34·77	1·50	0·25	0·20	0·94	0·38	0·20	100·41	83·38	7·92	18·31	1·50	0·20	33	20	8	
41	59·80	1·38	36·12	1·09	0·25	0·40	0·60	0·46	0·06	100·16	87·5	6·4	16·8	1·09	0·40	32	26-27	5-6	
42	59·74	1·79	34·07	2·34	0·37	0·30	1·06	0·28	0·24	100·19	81·55	8·04	18·79	2·34	0·30	30-31	16	4-5	
43	58·94	1·51	32·89	1·72	1·21	0·86	1·56	0·78	0·40	99·87	69·7	12·9	15·1	1·6	0·8	30-31	16-17	9	
44	58·78	1·31	31·98	5·31	0·60	0·54	0·78	0·66	0·12	100·08	69·1	7·8	17·7	4·8	0·5	29-30	14	10-11	After Contraction 0·17%
45	57·72	1·47	36·11	2·81	0·46	0·36	1·00	0·30	0·06	100·29	86·7	7·8	14·3	2·81	0·36	31	16-17	9-10	After Contraction 0·27%
46	57·45	1·92	36·05	2·44	0·25	0·64	0·50	0·52	0·17	99·94	78·24	5·48	13·60	2·18	0·57	32-33	16-17	11	After Contraction nil.
47	57·28	1·67	36·28	2·56	0·34	0·48	0·94	0·58	0·20	100·33	86·7	9·1	12·7	2·56	0·48	32	17-18	9-10	
48	56·62	1·92	38·55	1·40	0·32	0·30	0·70	0·20	0·18	100·19	94·0	5·4	11·8	1·4	0·3	32-33	19	8-9	After Contraction nil.
49	56·00	1·25	37·00	2·19	0·51	0·64	1·84	0·68	0·20	100·31	76·9	13·5	7·0	1·9	0·6	33	18	10	
50	55·08	1·43	37·48	3·44	0·31	0·51	1·31	0·39	0·20	100·15	79·5	9·1	7·9	3·1	0·5	31	17	9	
51	54·93	1·72	37·25	3·75	0·64	0·72	0·88	0·38	0·26	100·03	79·97	6·73	9·49	3·34	0·64	30	17	8	
52	54·52	2·00	37·66	3·44	0·47	0·28	1·04	0·32	0·23	99·96	90·48	8·16	9·60	3·44	0·28	32-33	17-18	10	
53	53·78	3·40	39·57	1·75	0·06	0·18	0·60	0·52	0·14	100·00	84·5	5·9	7·5	1·7	0·2	33-34	19	9-10	After Contraction nil.
54	53·34	2·50	40·85	1·60	0·04	0·62	0·50	0·64	0·21	100·30	99·0	6·8	5·8	1·6	0·6	34	29	5	
55	52·79	2·50	30·93	1·33	0·81	0·63	0·98	0·32	9·99	100·28	73·8	7·8	16·3	1·33	0·6	31-32	14	12-13	
56	52·62	1·34	41·59	2·10	0·24	0·41	0·66	0·68	0·24	99·85	88·5	7·1	2·4	1·8	0·4	33-34	17-18	11	
57	52·46	1·24	40·65	3·27	0·37	0·78	0·41	0·72	0·18	100·08	86·90	5·97	3·51	2·88	0·69	> 35	17	> 13	
58	52·00	3·00	41·66	1·88	0·22	0·24	0·40	0·52	0·24	100·16	89·6	4·8	3·6	1·8	0·2	35	18	12	
59	51·40	2·06	42·32	1·32	0·27	0·52	0·88	0·50	0·28	99·55	90·04	7·35	1·02	1·16	0·45	> 35	26	> 9	After Contraction 0·35%
60	51·20	3·50	41·66	1·88	0·15	0·30	0·80	0·18	0·20	99·87	101·50	5·88	3·66	1·88	0·30	34	18	11	
61	51·02	2·50	43·52	2·00	nil	0·2	0·42	0·50	0·14	100·30	92·1	4·8	1·1	1·7	0·1	34	16-17	12-13	No Change. Cone 14, 2 hrs.
62	50·64	1·30	42·44	3·33	0·50	0·92	0·32	0·62	0·29	100·36	90·75	4·93	0·53	2·92	0·81	35	29	6	

There appears, however, to be an approximate relationship between the quartz and clay content (from calculated rational analyses) and the difference between the ordinary and under-load refractoriness (Fig. 1).

This is to be expected since the quartz-clay ratio is dependent to a large extent on the SiO_2 content.

(Results of a further consideration of these data will be included in a later report).

Under-load Refractory Test.—Present Procedure.

The present method of carrying out the refractory test under load is described in a previous paper by Dr. Mellor[4]. In practice, the material being tested is usually reported as failing under a known load, at that cone which has just fallen when the test piece itself has undergone a contraction of 7/12 in.; generally speaking, this degree of contraction does not take place until complete failure at the test piece has occurred. The result of the test, therefore, marks the temperature (in cones) of complete failure.

Furnace Modifications.

At the onset of this work, the external fittings of the present type of furnace were modified, at Dr. Mellor's request, with a view to

(*a*) Ensuring verticality of the applied load, and eliminating the possibility of shearing forces acting on the test piece.

(*b*) Enabling the behaviour of a refractory, under load at elevated temperatures, to be followed.

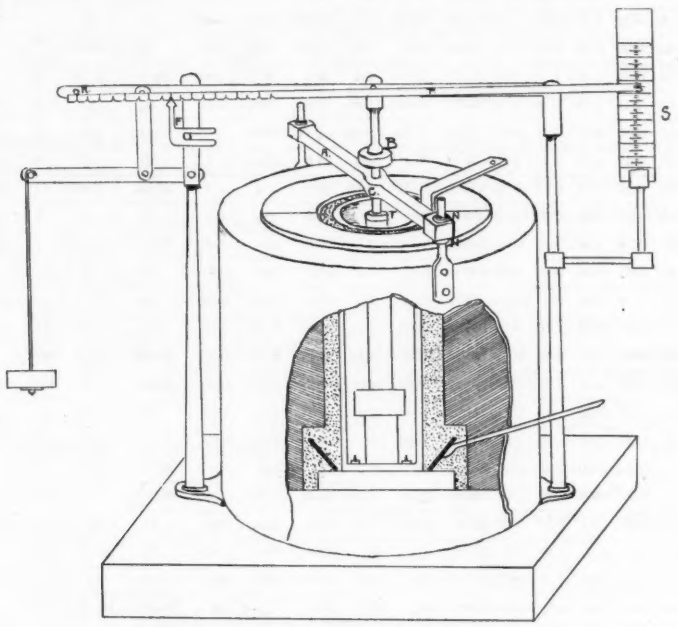


Fig. 2.—Modified Under-Load Test Furnace.

The additions consist of :—

(1) A vertical collar (*c*) drilled through a horizontal arm (*A*); by means of adjusting nuts *N*, at the extremities of this arm, the short thrust rod *T* passing through the collar is easily and rapidly adjusted to a vertical position.

(2) A cup and ball arrangement at *B* for the transference of the thrust from the main lever arm to the thrust rod.

(3) A graduated, notched aluminium rod, *P*, 42 in. long, supported on a movable knife-edge fulcrum, *F*. Cross-wires placed in a slot at the extremity of this rod move over a scale, *S*.

By means of this arrangement, vertical movement of the test piece (and supports), heated under load, may be recorded with a magnification of from 10/1 to 40/1, according to the position of the fulcrum and the relative lengths of the recorder arms.

Experimental, A.—Fireclays with Fireclay Grog.

Grog.—Prepared from the clay with which it was to be used, moulded in small pieces, dried and subjected to two china-biscuit firings, ground in a jaw-crusher, and separated into four fractions. In all the work included in this report, a constant grog grading was used, viz. :—

Thro' 4's on 8's.	Thro' 8's on 16's.	Thro' 16's on 30's.	Thro' 30's.
30%	30%	30%	10%

Mixing, Moulding, &c.

Mixing and tempering were carried out by hand, and the briquettes were slop-moulded in a wooden mould. With each clay used, four sets of briquettes were prepared, viz. :—

(1) Straight Clay.
(2) 20 p.ct. grog content.
(3) 40 p.ct. grog content.
(4) 60 p.ct. grog content.

Firing.

The whole of the test bricks were fired in a commercial kiln to a temperature corresponding to cones 13–14.

Determinations.

(1) Ultimate chemical composition and calculated rational analysis.
(2) Relative grain-size composition of raw clays expressed as surface factors.
(3) Porosity and apparent specific gravity.
(4) True specific gravity.
(5) Contractions on drying and firing.
(6) Refractoriness.—In cases of doubt, this test was carried out in duplicate.
(7) Behaviour under load at high temperatures.

ANALYSIS OF RAW MATERIALS.

Clay Lab. Mark ..	*S*	*B*	*C*	*M*	*A*
Silica (SiO_2) ..	64·30	50·25	47·56	46·39	43·40
Titanic Oxide (TiO_2)	1·32	0·91	—	1·58	3·35
Alumina (Al_2O_3) ..	21·34	33·26	38·50	36·26	36·89
Ferric Oxide (Fe_2O_3)	1·88	1·62	0·62	1·59	0·69
Magnesia (MgO) ..	0·51	0·22	0·03	Trace	Trace
Lime (CaO) ..	0·34	0·63	0·29	0·56	0·78
Potash (KO) ..	1·02	2·66	1·32	0·50	0·50
Soda (Na_2O) ..	0·084	0·50	0·10	0·60	0·26
Loss	8·9	9·79	12·02	13·93	14·1

CALCULATED RATIONAL ANALYSIS.

Clay	60·0	75·5	90·5	81·6	93·5
Felspar	6·5	18·6	8·3	7·2	4·9
Quartz	36·4	3·1	nil	8·9	nil
Ferric Oxide ..	1·88	1·62	0·62	1 6	0·69
Lime	0·34	0·63	0·29	0·56	0·78
			Excess Al_2O_3		Excess Al_2O_3

PHYSICAL DATA.

	% vol. contraction (a) Wet—dry (b) Dry—fired		True sp. gr.	App. sp. gr.	% Porosity.
	(a)	(b)			
S. Straight clay	21·81	34·06	2·47	2·06	14·79
S. 20% grog ..	16·69	23·90	2·55	1·87	26·73
S. 40% ,, ..	7·08	12·84	2·56	1·72	32·28
S. 60% ,, ..	6·80	—	2·55	1·72	32·01
B. Straight clay	29·45	50·98	2·40	2·37	1·14
B. 20% grog ..	18·35	40·65	2·40	2·17	9·94
B. 40% ,, ..	17·74	26·80	2·46	1·92	21·84
B. 60% ,, ..	8·20	14·37	2·47	1·82	27·01
C. Straight clay	11·69	34·87	2·58	1·98	21·8
C. 20% ,, ..	6·10	31·39	2·69	1·74	35·47
C. 40% ,, ..	1·80	20·20	2·73	1·61	40·35
C. 60% ,, ..	—	16·70	2·71	1·61	40·49
M. Straight clay	11·94	18·32	2·68	2·10	21·64
M. 20% grog ..	11·94	6·41	2·65	1·91	27·71
M. 40% ,, ..	4·46	2·33	2·65	1·80	33·53
M. 60% ,, ..	very low		2·63	1·71	34·09
A. Straight clay	9·82	30·08	2·75	2·03	26·10
A. 20% ,, ..	6·12	7·81	2·75	1·72	37·32
A. 40% ,, ..	3·14	3·12	2·73	1·60	40·10
A. 60% ,, ..	very low		2·73	not detd.	not detd.

Grain-Size Analysis of Raw Clays.

The raw clays as used, *i.e.*, ground to pass a 20's sieve, were separated into four fractions by sieving and elutriation. The velocity of the water flow during elutriation was calculated to carry away particles of diameter 0·01 mms. In each case 10 grms. of raw clay were shaken mechanically for six hours in water rendered just alkaline by addition of a few drops of NH_4OH. The weights of the various fractions obtained are given below, together with the calculated surface factor[1].

	Stays on 120's lawn	Passes 120's on 200's	In Elutriator	Carried over	Surface factor
Mean dia.	423 mm.	0·087	0·042	·0063	
S ..	0·96	0·45	2·39	8·20	237·95
B ..	0·537	0·793	3·705	4·92	198·14
C ..	nil	0·15	1·46	8·39	309·46
M ..	5·18	0·86	1·87	2·19	93·68
A ..	5·35	0·93	1·74	1·98	85·71

ORDINARY REFRACTORINESS.
Raw Materials.

	S	B	C	M	A
Cones ..	29	30	>35	33	>33/34
°C. ..	1650	1670	>1770	1730	>1740

FIRED PRODUCTS. (Cones and Approx. °C.).

Grog ..	S	B	C	M	A
Straight clay ..	30 1670°	31 1690°	>35 >1770°	32 1710°	>35 >1770°
20% ..	29 1650°	31-32 1700°	>35 >1770°	32 1710°	>35 >1770°
40% ..	29 1650°	32 1710°	>35 >1770°	32-33 1710°	>35 >1770°
60% ..	29 1650°	32 1710°	>35 >1770°	33-34 1740°	>35 >1770°

Behaviour of Refractory Material Under Load at Elevated Temperatures.

It was decided, in order to obtain results comparable with those previously tabulated in the introduction to this report, to proceed with the under-load test as at present carried out, following the movement of the test pieces from the temperature at which thermal expansion ceases.

In the curves of Series I which follow, linear changes of the test piece beyond this temperature are plotted against temperature indicated by cones, the heating being stopped when the test piece has undergone a contraction of approximately $\frac{1}{2}$ in. Except in the case of the C briquettes, this range of subsidence included the point of complete failure.

[SUBS. NOTE.—With reference to Figs. 3, 4, 5, 6, and 7 the abscissæ represent merely cones. The centigrade temperatures should be deleted and corresponding cone temperatures inserted. *c.f.* standard cone-temp. table.]

Discussion of Curves of Series I.

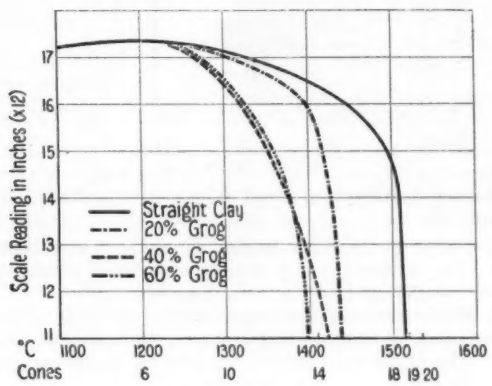


Fig. 3.—Series I. *S.*

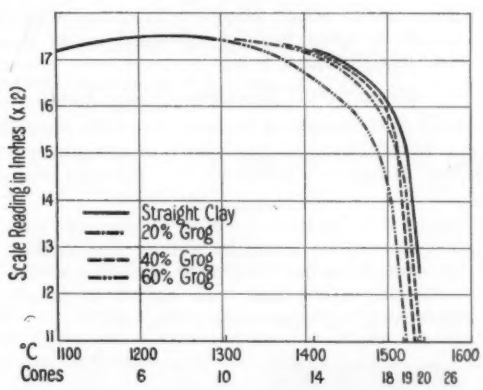


Fig. 4.—Series I. *B.*

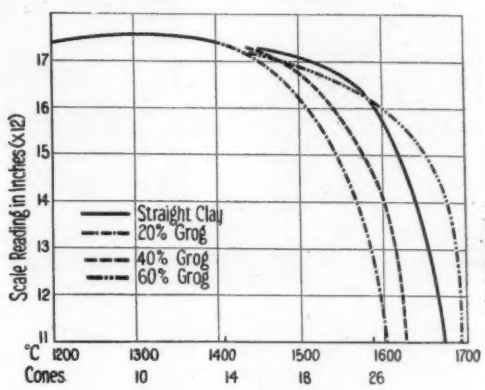


Fig. 5.—Series I. *C.*

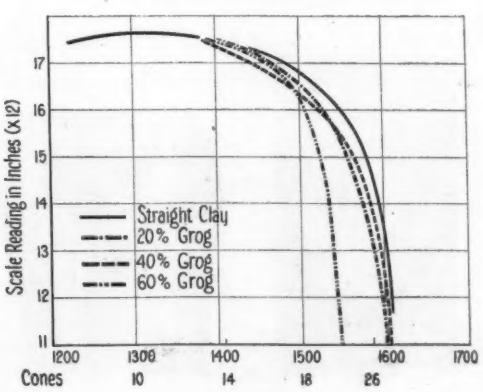


Fig. 6.—Series I. *M.*

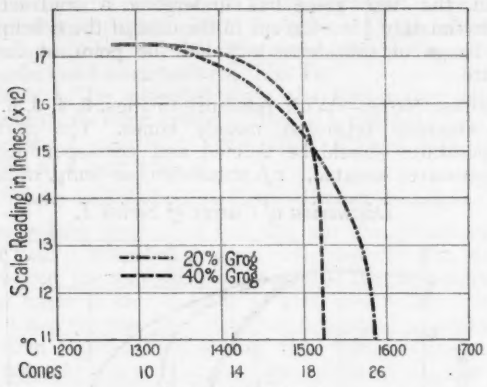


Fig. 7.—Series I. *A*.

Three conclusions are arrived at from a study of these curves, viz. :—

(1) For a specific clay heated up under a constant load, the temperature at which subsidence commences is independent of the grog content.

(2) With the refractories examined, there is a variable range of temperature between the commencement of the under-load subsidence and the point of complete failure.

(3) With one exception (C 60 p.ct. grog), the temperature at which complete breakdown under load occurs is lower with the grogged bricks than with the straight clays.

Mechanism of Breakdown Under Load.

From an examination of the various pieces after the test, it is concluded that the breakdown of refractory material under load at high temperatures may occur in one of three ways.

(*a*) Straight subsidence. No bulging of test piece. Appears to be absolute volume contraction. This type of subsidence occurred with the whole of the *C* bricks, which had been shown to possess comparatively high porosities. (Fig. 8).

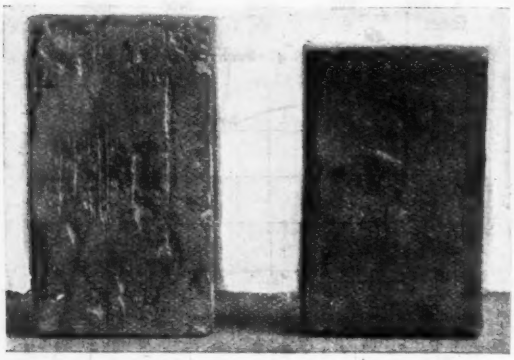


Fig. 8.

(*b*) Subsidences with bulging of sides of piece accompanied by vertical planes of cleavage. Shown by the *B*, *S*, and *M* straight clays; the *S* 20 p.ct. grog; and the grogged *M* and *A* pieces. (Fig. 9).

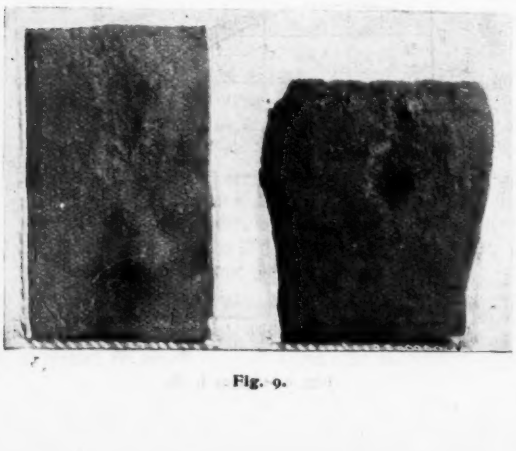


Fig. 9.

(*c*) Subsidence accompanied by a diagonal plane of cleavage, similar to the type of break occurring with cast iron and timber tested to the breaking point under compressive stress. The cleavage plane is inclined at about 45° to the horizontal. Obviously some softening has occurred, for the two portions of the test piece hold together, although in some cases the top portion is displaced laterally to the extent of $\frac{1}{8}$ in., shown by the *B* and *S* grogged pieces (except *S* 20 p.ct. grog). (Fig. 10).

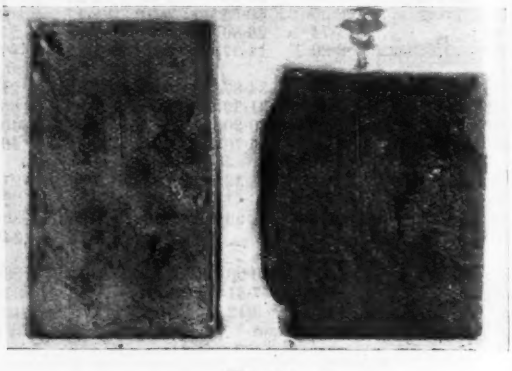


Fig. 10.

Behaviour of Refractory Material Under Load at a Fixed Temperature.

Considering any one of the curves of Series 1, it is not permissible to conclude that the contraction which has occurred when a certain temperature is reached is a measure of the contraction which would take place if the piece were subjected to prolonged heating at that temperature. It is almost certain that the progress of the change preceding collapse is dependent not only on temperature itself, but also on the time of heating. In order to obtain quantitative data concerning linear changes of refractory material under a known load at some fixed temperature, the under-load test procedure was followed until a temperature of 1350° C. was attained. Then, by use of a variable carbon biscuit resistance, it was comparatively simple to keep the temperature at this value for any required time.

It was further foreseen that the modifications fitted to the furnace, and already described, opened up the possibility of the complete examination of the behaviour of a refractory under load at a fixed temperature, in so far as it might be possible to obtain—

(*a*) A general indication of the progress of thermal expansion under load.

(*b*) A more exact determination of the temperature at which thermal expansion under load ceases.

(*c*) An indication of the temperature range in which the dimensions of the refractory, under the load test, remain more or less constant.

(*d*) An indication of the temperature at which contraction under load commences.

(*e*) A measure of the contraction occurring under load at a fixed temperature (1350°).

(*f*) By measuring the length of the piece before and after the test (cooled slowly overnight), by means of vernier calipers—a determination of what may be termed "after-contraction under load."

It would only be possible, with the present type of furnace, to make an absolute determination of the thermal expansion under load if the thrust-rod and supports could be kept at a constant temperature throughout the test, or expanded by a known amount for a known test-piece temperature. While neither of these ideal conditions has, as yet, been attained, it has been found possible to prepare a standard test piece and thrust-rod which show a regular thermal expansion up to a test-piece temperature of 1400° C. Furthermore, the vertical dimensions of this standard test piece and thrust-rod remain almost constant at this temperature for a prolonged period (3 hours).

Preparation of Standard Test Pieces and Thrust-Rod.

The preparation of the standard test piece was finally effected by subjecting a *C* clay briquette to three successive

firings, under a load of 75 lbs. per sq. inch, to a temperature of cone 26 down. The cylinders comprising the thrust-rod were treated in a similar manner. Both the carborundum block, placed immediately above the test piece, and the commercial carbon brick upon which the test piece rests, had been in use in another furnace for some considerable period.

Standard Reference Curve.

A preliminary experiment was carried out with the specially prepared thrust-rod cylinders extending from top to bottom of the furnace. This rod, subjected to a load of 50 lbs. per sq. inch and a two hours' heat soaking at a temperature of 1300° C. at the test-piece zone, showed negligible contraction. A further experiment carried out with the standard test piece, heated under a load of 50 lbs. per sq. inch to a temperature of 1400° C., showed a regular thermal expansion. Furthermore, the linear dimensions in a vertical direction remained practically constant during a three hours' heat-soaking at this temperature.

The results of this determination were plotted, linear changes as ordinates, and temperature and time as abscissæ, and are recorded in the Standard Curve (see graph Series II., Fig. 11). The behaviour of other refractory material under load at high temperatures may be compared with this curve.

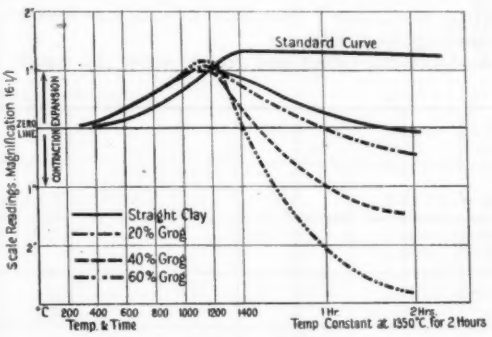


Fig. 11.—Series II. *S*.

Discussion of S Curves of Series II.

Having formulated a standard reference curve, an investigation of the behaviour of the *S*, *B*, *C*, *M*, and *A* straight clay and grogged briquettes under this modified test was undertaken.

The results obtained with the *S* Series are appended (graph Series II.), and discussed briefly, as indicating the scope and general utility of this new method of investigation.

Results.

Temperature readings were obtained by the use of a standardized Pt, Pt.-Rh. couple; the hot junction being kept in contact with the centre of a face of the test piece.

Heat Gradient of Thrust-Rod.

In order to limit the unknown factors as far as possible, the temperature gradients of the supports, one hour after the test piece had assumed a temperature of 1350° C, were taken.

TEMPERATURE GRADIENTS OF THRUST-ROD.

	Standard Piece (a)	Standard Piece (b)	Straight *S*	*S* 20% grog	*S* 40% grog	*S* 60% grog
Top of carborundum block	1210° C.	1200	1210	1210	1200	1230
Middle bottom cylinder ..	1190	1195	1185	1200	1180	1220
„ 2nd „ ..	1120	1100	1105	1130	1100	1130
„ 3rd „ ..	990	990	990	1005	970	1030
„ 4th „ ..	810	825	825	810	830	850
„ 5th „ ..	630	640	655	620	660	640
„ top „ ..	450	450	420	420	430	440

LENGTH OF PIECES BEFORE AND AFTER TEST (in cms.).

	Straight *S*	*S* 20%	*S* 40%	*S* 60%
Before test ..	8·974	9·12	9·01	9·205
After test ..	8·830	8·92	8·76	8·735
After contraction under load ..	1·60%	2·19	2·65	5·160

Comparative Contractions at 1350° C.

The following figures are obtained from the graph, and must be understood to indicate only comparative contractions occurring at 1350° C. They are to be distinguished from the "After-Contractions under Load" which are equal to the contractions occurring at 1350° C., *plus* a further contraction taking place on cooling.

Contractions at 1350° C. (compared with behaviour of standard piece at 1350° C.).

	Straight *S*		*S* 20% grog		*S* 40% grog		*S* 60% grog	
	cms.	ins.	cms.	ins.	cms.	ins.	cms.	ins.
Comparative contraction at 1350° for 2 hrs.	0·20	0·08	0·28	0·11	0·44	0·17	0·64	0·25

From a study of the curves of Series II. *S*, there is evidence that, for a clay of the *S* type, the rate and amount of subsidence under load at a fixed temperature is related, within limits, to the proportion of grog, *i.e.*, the greater the proportion of grog, the more rapid the subsidence and the greater its amount.

The remaining curves of Series II. will be presented as a supplement to this report, together with the results of a complete examination of a typical selection of commercial firebrick products.

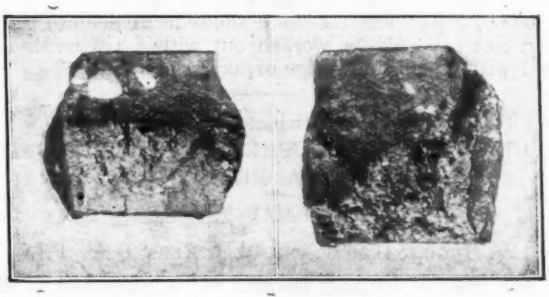
REFERENCES.

(1) J. W. Mellor and B. J. Moore, *Trans. Inst. Gas Eng.*, 1916, 70.
(2) J. W. Mellor and W. Emery, Ibid., 1918, p. 71.
(3) W. Emery and L. Bradshaw, Ibid., 1919-20, p. 93.
(4) L. Bradshaw and W. Emery, Ibid., 1920-21, p. 326.
(5) J. W. Mellor, Standardization of Tests, Ibid., 1918.
(6) J. W. Mellor, *Trans. Cer. Soc.*, 9, 106, 1910.

(C) NOTE ON REFRACTORINESS UNDER LOAD.*

J. W. MELLOR, D.Sc.

The difficulty in trying to get a relation between the physical and chemical characters of a firebrick and its squatting temperature under load is partly due to the difficulty in distinguishing two distinct types of fracture. The two types are illustrated by the appended diagram. In one, the brick breaks down mechanically, as illustrated below, although the difference is not always so clearly defined as this. As the temperature rises, the brick seems to pass through a temperature zone where it becomes brittle. If it passes through this region safely, then it may subsequently squat by the second type of breakdown, which is really evidence that the brick is approaching its fusion temperature. This type was fully described by J. W. Mellor and B. Moore, *Trans. Inst. Gas Engineers*, p. 70, 1916; *Trans. Cer. Soc.*, 15, 117, 1915.



Photographs Illustrating the Two Types of Fracture of Firebricks.

The results given in the table of Mr. Dale's paper in *Bulletin* 5, pp. 22–25, illustrate exceedingly well the sort of thing we come across in practice. On making further enquiries, I have power to say that the extraordinary result with Brick No. 11 is connected with the fact that the brick had been in use for several months, and was an apparently sound brick taken from a dismantled furnace. From the fact that it had been in the "prick" of the furnace so long, the brick must have been exceedingly well fired, or, as the workman would express it, the brick had lost its "nature" by the prolonged firing.

* Bulletin 6, p. 6, B.R.R.A., April, 1924.

(*D*) SHORT SUMMARY OF "SEDIMENTATION AS A MEANS OF PURIFYING CLAY."*

By S. R. HIND, B.Sc.

The suitability of a clay for purification by this method depends on the concentration of the bulk of the impurities in the coarsest fraction. Preliminary weathering is necessary with shales. Flint clays are fireclays containing refractory fireclay nodules, and are not suitable for treatment. A small proportion of deflocculant (sodium carbonate, silicate of soda, etc.) is added during or after deflocculation to destroy the gelatinous nature of the clay, and to economize in water. The various phenomena of deflocculation, coagulation, and settling are pointed out, and certain theoretical conceptions enunciated. Acidity or alkalinity alone cannot cover the facts. The clay grains possess a selective chemical power depending on their surface area. Silicate of soda appears to stabilize clay suspensions by coating the particles with gelatinous silicic acids, thereby masking the normal reactions of the clay. Normal (coagulated and gelatinous) clay slips and plastic clay masses contain water in a "fixed" or non-fluid condition, and this is intimately bound up with plasticity. The clay appears to act as a semi-permeable membrane around this water. Hydrostatic pressure alone has a great effect in de-watering clay.

In the case of a North Staffordshire fireclay, sedimentation

(1) reduced the percentage of iron, notably without eliminating it entirely, having little effect on titania, alkalis, and alkaline earths;

(2) gave a finer-grained product and increased the refractoriness and contraction on drying and on firing.

Where the clay was removed electrically from the slip (osmosis process). no further practical improvement could be detected. The osmosis process was found to be very costly with the local clay in question. With Karlsbad kaolin, the clay forming the purified slip fed to the osmosis machines had thesame refractoriness (Cone 35) as, and closely similar analysis to, the material obtained from the machine. A detailed description of the process in use at Karlsbad is available to members of the British Refractories Research Association.

Various methods of treating clay, depending on its nature and other conditions, are summarized. It is estimated that treatment by settling and filter-pressing would, under favourable conditions, cost about 13s. per ton for a continuous output of 100 tons per week, and a capital expenditure of about £10,000, 5 p.ct. interest being allowed. A definite process and cost can only be worked out with a particular clay, and with a full knowledge of local conditions.

(*E*) THE EFFECT OF REPEATED BURNING ON THE STRUCTURE AND PROPERTIES OF LIME-BONDED SILICA BRICKS.†

PART I.

W. HUGILL, B.Met., AND W. J. REES, B.Sc., F.I.C.

The effect of repeated burning on the properties of silica bricks has been previously examined by J. S. McDowell, using lime-bonded bricks made from Medina quartzite.[1] He concludes from reburnings carried out on 9 by 4½ by 2½ in. bricks in commercial kilns that the uniformity of strength of a given lot of bricks diminishes with repeated burning; slightly in compression, considerably in cross-breaking. On the first burn, the larger part of the quartz was transformed into cristobalite, and on repeated burning the remaining quartz was very slowly transformed. The cristobalite, at first slowly and later more rapidly, inverted to tridymite. The temperature of the burnings was cones 14–15. D. W. Ross[2] has also made experiments on the effect of repeated burning, but his tests were made on 2-in. cubes burned in a laboratory furnace under conditions which would be essentially different from those in a commercial kiln.

To observe the effect of repeated burning on lime-bonded bricks made from Sheffield ganister, a batch of 44 bricks (9 by 4½ by 3 in.) was taken without special selection from the ordinary commercial make at the Mooredge Brickworks of Messrs. Pickford, Holland, & Co., Ltd. One of the raw bricks was broken down and examined for grading. The grading analysis gave:—

Through	5	and on	10	mesh	sieve	..	5·8	per cent.	by weight
,,	10	,,	20	,,	,,	..	22·0	,,	,,
,,	20	,,	30	,,	,,	..	7·0	,,	,,
,,	30	,,	40	,,	,,	..	2·0	,,	,,
,,	40	,,	50	,,	,,	..	1·7	,,	,,
,,	50	,,	60	,,	,,	..	1·0	,,	,,
,,	60	,,	80	,,	,,	..	3·0	,,	,,
,,	80	,,	90	,,	,,	..	4·7	,,	,,
,,	90	,,	120	,,	,,	..	26·3	,,	,,
,,	120	,,	200	,,	,,	..	5·8	,,	,,
	Through		200	,,	,,	..	20·7	,,	,,
							100·0	,,	,,

The bricks, with distinguishing marks on them, were then set together in the kiln. After the first burn, four bricks were put aside for examination, and the remainder were reburned in the next kiln, and so on. In all, eleven reburnings were made. No special precautions were observed in handling the bricks.

The following tables and graphs show the results of the tests made on the bricks. The compression and transverse tests were each made on two bricks from each reburn.

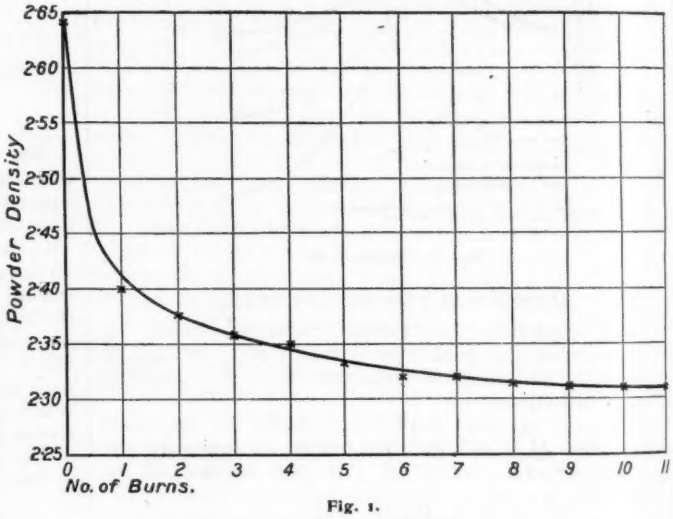


Fig. 1.

Powder Density.—As shown in Table I. and Fig. 1., the major part of the inversion was accomplished in the first burn, but there was a steady decrease in the proportion of unchanged quartz down to the seventh burn. The results indicate the importance of the "soaking" period of the burn. It is a reasonable assumption that if, in the first burn, the maximum temperature had been held, without any increase in temperature, for twice as long, the powder density would have been at least as low as that shown for the second burn.

Volume Changes.—As shown by the mean volumes of the bricks in Table I., there is very little change in volume after the first burn, the linear expansions measured being negligible. There is a steady fall in *porosity* down to the seventh burn, after which it remains fairly constant (Fig. 2). It is evident that, after the first burn, most of the inversion has taken place by an interlacing crystallization or crystal growth of cristobalite and tridymite in the melt.

Mechanical Strength.—The increase in crushing strength up to the seventh burn is noteworthy, and the gradual increase in toughness after the sixth burn was particularly noticeable. As shown in Table III. and Fig. 4, there is a steady increase in the transverse strength up to the fifth

* Bulletin 6, p. 28, B.R.R.A., April, 1924.
† Bulletin 6, p. 18, B.R.R.A., April, 1924.
[1] A study of the silica refractories, J. S. McDowell, *Trans. Amer. Inst. Min. Eng.*, 1917
[2] Silica Refractories, *Tech. Papers Bureau of Standards*, No. 116.

TABLE I.

Burn	Temp. of Burn		Dimensions cms.	Volume c.c.	Weight gms.	Apparent density	Powder density	Porosity
0			22·3 ×10·6 ×7·6	1797	3651	1·87	2·640	29·1
1	16	*a*	23·27×11·21×7·93	2069	3415	1·65	2·380	30·6
,,		*b*	23·10×11·40×7·94	2091	3495	1·67	2·405	30·48
,,		*c*	22·94×11·23×7·85	2022	3405	1·68	2·412	30·18
Mean 1st Burn			23·10×11·28×7·91	2061	3438	1·67	2·399	30·42
2	15	*a*	23·34×11·45×7·94	2122	3505	1·65	2·370	30·29
,,		*b*	23·04×11·20×7·98	2059	3385	1·65	2·382	30·98
,,		*c*	23·20×11·20×7·81	2027	3440	1·68	2·383	29·50
,,		*d*	22·96×11·07×7·80	1983	3335	1·68	2·380	29·33
Mean 2nd Burn ..			23·14×11·23×7·88	2048	3416	1·665	2·379	30·03
3	16	*a*	23·19×11·35×7·87	2015	3440	1·66	2·350	29·32
,,		*b*	23·06×11·38×7·87	2065	3490	1·69	2·355	28·25
,,		*c*	23·20×11·46×7·93	2107	3495	1·66	2·352	29·42
,,		*d*	22·96×11·40×7·87	2060	3525	1·70	2·368	28·21
Mean 3rd Burn			23·10×11·40×7·89	2062	3488	1·68	2·356	28·80
4	16	*a*	23·00×11·18×7·77	1997	3395	1·70	2·352	27·72
,,		*b*	23·26×11·38×7·96	2107	3540	1·68	2·355	28·66
,,		*c*	22·96×11·33×7·87	2047	3505	1·71	2·355	27·39
,,		*d*	23·00×11·27×7·84	2023	3375	1·66	2·355	29·51
Mean 4th Burn.. ..			23·06×11·29×7·86	2044	3454	1·69	2·354	28·32
5	16	*a*	23·10×11·29×7·78	2029	3420	1·69	2·335	27·62
,,		*b*	23·14×11·41×7·94	2096	3540	1·68	2·328	27·84
,,		*c*	23·02×11·25×7·77	2012	3350	1·67	2·335	28·48
,,		*d*	23·00×11·30×7·82	2032	3410	1·69	2·330	27·47
Mean 5th Burn.. ..			23·07×11·31×7·84	2042	3430	1·68	2·332	27·85
6	15–16	*a*	23·16×11·52×7·90	2108	3560	1·69	2·320	27·16
,,		*b*	23·20×11·40×7·85	2076	3520	1·695	2·315	26·78
,,		*c*	23·21×11·39×7·77	2054	3465	1·69	2·325	27·44
Mean 6th Burn.. ..			23·19×11·43×7·84	2079	3515	1·692	2·320	27·13
7	16	*a*	23·04×11·09×7·77	1985	3370	1·697	2·323	26·95
,,		*b*	23·00×11·16×7·85	2015	3415	1·695	2·322	27·00
,,		*c*	23·12×11·26×7·89	2054	3505	1·706	2·322	26·53
,,		*d*	23·20×11·40×7·90	2089	3495	1·673	2·315	27·73
Mean 7th Burn.. ..			23·09×11·23×7·85	2036	3446	1·693	2·320	27·05
8	16	*a*	23·20×11·19×7·80	2027	3365	1·709	2·317	26·24
,,		*b*	23·03×11·31×7·94	2069	3480	1·682	2·310	27·19
,,		*c*	23·19×11·30×7·76	2032	3440	1·693	2·315	26·87
,,		*d*	23·18×11·45×7·90	2097	3535	1·686	2·315	27·17
Mean 8th Burn.. ..			23·15×11·31×7·85	2056	3455	1·693	2·314	26·87
9	15–16	*a*	23·13×11·50×7·93	2109	3550	1·683	2·312	27·20
,,		*b*	23·25×11·35×7·89	2082	3540	1·700	2·313	26·50
,,		*c*	23·18×11·43×7·85	2080	3485	1·675	2·315	27·64
,,		*d*	23·15×11·40×7·85	2072	3480	1·680	2·315	27·43
Mean 9th Burn			23·18×11·40×7·88	2086	3514	1·685	2·314	27·19
10	16	*a*	23·15×11·10×7·68	1974	3370	1·708	2·310	26·06
,,		*b*	23·15×11·31×7·93	2062	3500	1·699	2·310	26·45
,,		*c*	23·15×11·43×7·93	2098	3500	1·668	2·312	27·85
,,		*d*	23·16×11·49×7·94	2113	3550	1·680	2·312	27·39
Mean 10th Burn ..			23·15×11·33×7·87	2062	3480	1·689	2·311	26·92
11	16	*a*	23·09×11·25×7·70	2000	3350	1·675	2·310	27·49
,,		*b*	23·26×11·35×7·73	2041	3425	1·679	2·305	27·16
,,		*c*	23·23×11·30×7·97	2092	3530	1·687	2·310	26·97
			23·19×11·30×7·80	2044	3435	1·680	2·308	27·25

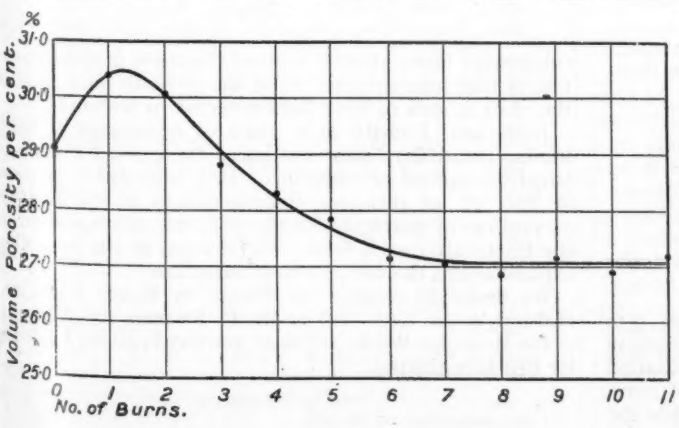


Fig. 2.

burn, but from that point the tests are inconclusive. It is likely that the alternate expansions and contractions in the reburning have caused the formation of minute cracks in the brick, which would have little effect on the resistance of the bricks to crushing loads, but would adversely affect their resistance to transverse loads. There is no doubt from these results that lengthening the duration of the "soaking" period of the burn will decidedly increase the mechanical strength of the bricks.

Chemical analyses have been made of bricks from the first and eleventh burn, and it is shown that there is no change in composition resulting from the repeated burning of the bricks.

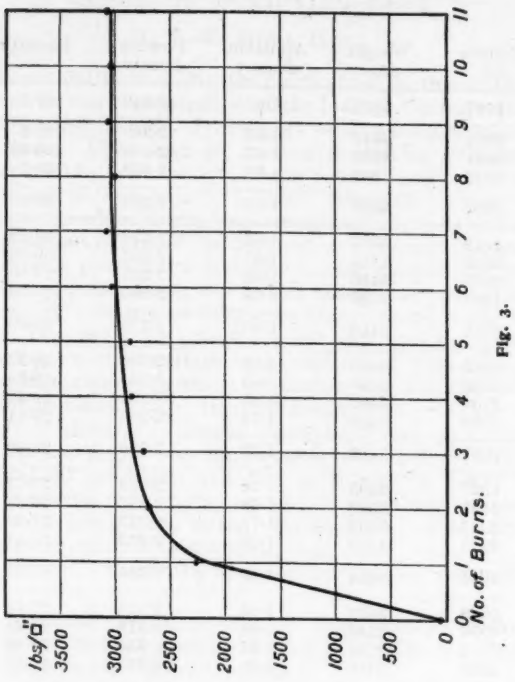


Fig. 3.

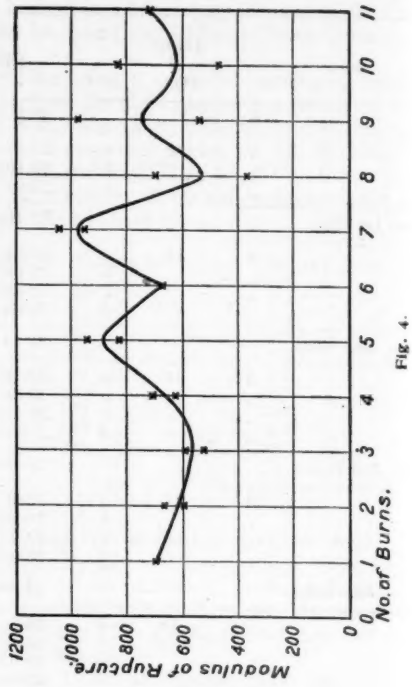


Fig. 4.

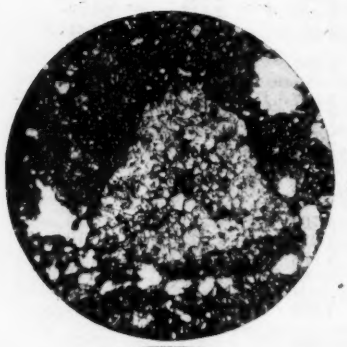


Fig. 6.
3rd Burn (× 16).

Fig. 8.
6th Burn (× 16).

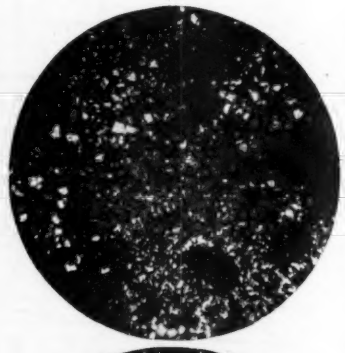


Fig. 10.
Crossed nicols (× 16).
11th Burn.

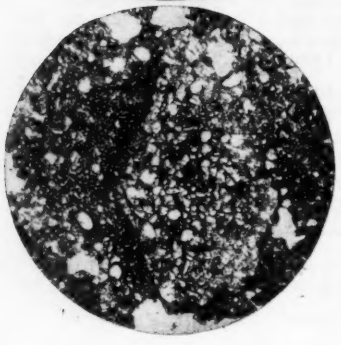


Fig. 5.
1st Burn (× 16).

Fig. 7.
4th Burn (× 16).

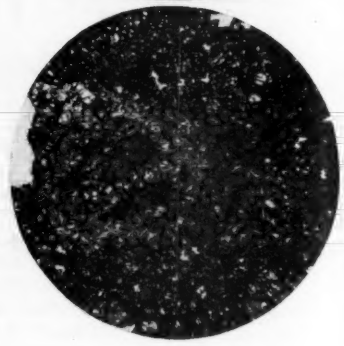


Fig. 9.
8th Burn (× 16).

	First Burn	Eleventh Burn
SiO_2	95·45	95·55
TiO_2	0·32	0·30
Al_2O_3	0·90	1·10
Fe_2O_3	0·68	0·70
CaO	1·85	1·81
MgO	0·25	0·31
Alkalies as K_2O	0·25	0·22
Loss on ignition	0·22	0·18
	99·92	100·17

Changes in Structure.—The photomicrographs (Figs. 5 to 10) show clearly the changes in structure, and the decrease in the size of the quartz grains; the gradual recrystallization in the matrix being well shown. After the second burn, crystals of tridymite appear in the ground mass, and in the subsequent burns there is a steady increase in the proportion of tridymite present. After the eleventh burn most of the silica is seen to have been inverted to tridymite.

Rieke and Endell[1], in a series of reburnings of silica bricks, found that after ten burns the ground mass was largely composed of tridymite. It is intended to present in Part II. of this note determinations of the relative proportions of quartz, tridymite, and cristobalite present in the bricks after each burn; the changes in the reversible expansion and the refractoriness under load.

We desire to express our thanks to Messrs. Pickford, Holland, & Co., Ltd., and to Mr. R. Bramall, the Manager of the Mooredge Works, for their courtesy in giving facilities for this investigation.

1 *Zeits. anorg. Chem.*, 26, 239, 1913.

TABLE II.

CRUSHING STRENGTH OF BRICK ON END.

Burn	Number	Dimensions ins.	Area sq. ins.	Crushing Load lbs.	Compression Strength lbs./□"
*0		4·20×3·00	12·6	873·6	69
1	*a*	4·42×3·11	13·75	25,222	1885
	b	4·50×3·13	14·08	38,595	2740
Mean 1st Burn ..					2287
2	*a*	4·51×3·12	14·07	37,172	2642
	b	4·41×3·13	13·80	38,650	2800
Mean 2nd Burn ..					2721
3	*b*	4·48×3·10	13·89	38,750	2790
	d	4·40×3·10	13·64	38,028	2724
Mean 3rd Burn ..					2757
4	*a*	4·40×3·06	13·46	38,180	2836
	c	4·46×3·10	13·83	40,107	2900
Mean 4th Burn ..					2868
5	*c*	4·43×3·06	13·55	40,650	3000
	d	4·45×3·08	13·70	37,960	2771
Mean 5th Burn ..					2885
6	*a*	4·54×3·11	14·12	42,370	3001
	b	4·49×3·09	13·87	42,500	3064
Mean 6th Burn ..					3032
7	*b*	4·39×3·09	13·57	42,067	3100
	d	4·49×3·11	13·96	42,578	3050
Mean 7th Burn ..					3075
8	*a*	4·41×3·07	13·54	40,620	3000
	d	4·51×3·11	14·03	42,090	3000
Mean 8th Burn ..					3000
9	*b*	4·47×3·11	13·90	41,750	3004
	d	4·49×3·09	13·87	42,600	3072
Mean 9th Burn ..					3038
10	*a*	4·37×3·02	13·20	40,000	3030
	c	4·50×3·12	14·04	42,150	3020
Mean 10th Burn ..					3025
11	*d*	4·47×3·04	13·59	41,800	3076
	c	4·43×3·14	13·91	41,700	2998
Mean 11th Burn ..					3037

* Only one brick was used.

TABLE III.

TRANSVERSE STRENGTH (distance between knife edges = l = 6 in.)

Burn	Number	Dimensions ins.	Breadth × (depth)²	Load in lbs. W.	Modulus of Rupture $R = \frac{3}{2}\frac{Wl}{bd^2}$
0	—	—	—	—	—
*1	*c*	4·42×3·09	42·20	3220	687
2	*c*	4·45×3·08	42·21	2800	597
	d	4·36×3·08	41·36	3080	670
Mean 2nd Burn ..					634
3	*a*	4·47×3·10	42·96	2520	528
	c	4·51×3·12	43·90	2688	588
Mean 3rd Burn ..					588
4	*b*	4·48×3·13	42·88	3416	701
	d	4·40×3·09	42·00	2940	630
Mean 4th Burn ..					615
5	*a*	4·44×3·06	41·73	4400	949
	b	4·49×3·13	43·99	4080	835
Mean 5th Burn ..					892
*6	*c*	4·49×3·06	42·04	3120	668
7	*a*	4·37×3·06	40·92	4320	950
	c	4·43×3·11	42·85	4960	1042
Mean 7th Burn ..					996
8	*b*	4·45×3·13	43·60	3360	694
	c	4·45×3·05	43·59	1760	363
Mean 8th Burn ..					529
9	*a*	4·53×3·22	46·97	2800	537
	c	4·50×3·09	42·00	4560	977
Mean 9th Burn ..					757
10	*b*	4·45×3·12	43·32	4000	831
	d	4·53×3·12	44·10	2320	474
Mean 10th Burn ..					653
*11	*a*	4·43×3·30	40·67	3280	726

* Only one brick was available.

(*F*) SOME CAUSES OF THE VARIATION IN THE SIZES OF REFRACTORIES—BRICKS AND BLOCKS.*

PART I.†

J. W. MELLOR, D.Sc.

From time to time, complaints are received from users about the varying sizes of firebricks. Irregular sizes necessitate irregular joints, with the result that too much bonding cement has to be used, and this is a notorious source of weakness. It is also said that in other countries firebricks can be obtained which have been ground true to size and shape. A significant omission in these complaints is the price. The user is not exactly fair when he will pay only a "seconds" price, and grumbles if he does not receive "firsts" quality. Any manufacturer would grind the bricks to Whitworth dimensions if it were worth his while; and a fair price could easily be arranged.

Putting aside the question of grinding, it is interesting to consider some of the more common causes of variations in the sizes of firebricks and blocks as they come from the kilns. In another branch of our industry, the electrical porcelain trade, a manufacturer would accept orders for goods made by the semi-dry process, without grinding, of dimensions 9 by 4½ by 3 in, with a variation of $\frac{1}{16}$ in. in length *plus* or *minus*, and the same proportions for the other dimensions. If the materials have to be made in a plastic clay, the variations acceptable would have to be approximately 50 p.ct. greater. These goods are made with the purest clays obtainable, by processes of manufacture exceedingly costly in comparison with those employed in making firebricks. When "absolute" accuracy is required in these industries, grinding has to be employed.

In a study of the causes of the variations in sizes of firebricks, some interesting features have appeared. The results emphasize how careful one must be in laying down general rules. A mode of treatment which will produce the best results with one clay may be the very process to give the worst results with another clay. Different clays may be compared with different human beings. Just as each man requires humouring in accord with his temperament to get the best results out of him, so does each clay require humouring in a special way to get the best from it.

Nothing is easier than for users to make specifications how firebricks should be made and fired, but the application of the specification may hinder progress, or even be a retrogression. In illustration, it is not uncommon to hear it said that every firebrick should be fired to cone 10; and a user may think that he is getting a super-firebrick or gas-retort if he specifies that it must be burned at cone 12 or

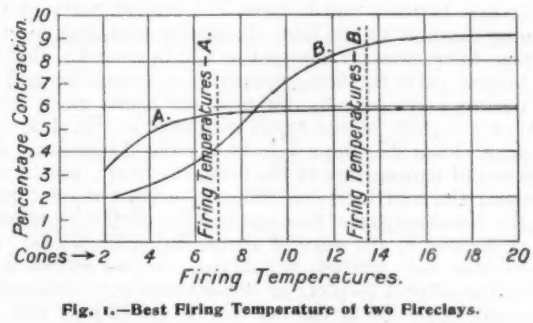


Fig. 1.—Best Firing Temperature of two Fireclays.

cone 14. We often hear, too, that some other country is ahead of us because they fire at cone 17 or even 18. The facts are, that *some fireclays will give as good a result when fired at cone* 4 *as other fireclays would give if fired at cone* 14. I should be very sorry if this statement were abused by a manufacturer firing kilns at cone 4 when they ought to be fired at cone 14.

The statement italicized may need demonstration; before doing so it is necessary to agree on some test. The contraction test recommended in the Gas Engineers' Specification is perhaps the best. I have selected two well-known fireclays, for which the contractions have been measured from

* Bulletin 6, p. 1, B.R.R.A., April, 1924.
† Part II. will probably appear in the next Bulletin.

time to time on a gradually rising temperature. The results are indicated in Fig. 1. Clay *A* contracts fairly quickly between cones 1 and 4; the rate then slackens until, at cone 7, contraction has almost ceased, and very little change occurs when the firebrick is heated at higher temperatures—even to cone 20. Clay *B*, however, is considerably underfired at cone 7, and must be fired to nearly cone 14 to get it in the condition which obtains with clay *A* at cone 7. It is hard luck on a manufacturer who has to deal with a clay like *B*, when his rival is working with one like *A*. It would be ludicrous if the manufacturer with clay *B* fired at cone 7, and the manufacturer with clay *A* fired at cone 14. So far as the contraction and porosity tests tell us, the extra firing with clay *A* consumes coal, punishes the kilns, and wastes time and capital to produce no result. To prevent any misunderstanding, I repeat that these remarks refer solely to results obtained with the contraction and porosity tests. The point I am developing

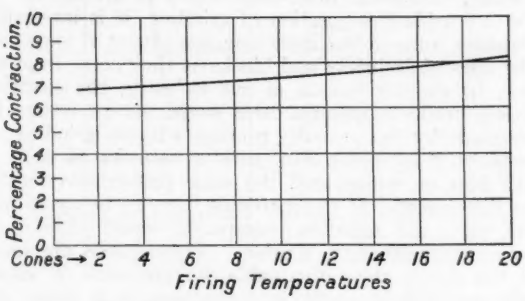


Fig. 2.—Fireclay with no "Best" Firing Temperature.

is that one fireclay can be as satisfactorily burned at, say cone 7, as another fireclay at cone 14.

A few hundreds of these tests have been made on different clays, and the types shown in Fig. 1 illustrate the sort of results obtained. Some clays show a rather steeper rise than is indicated between the dotted lines marked firing temperature and cone 20. This means that the firebricks should be then burned as near as possible to the temperature at which they have to be used; and in the extreme case illustrated by Fig. 2 the firing temperature seems never to be attained, because the clay never ceases to contract appreciably up to its fusion temperature. We can now apply these interesting results to the variations in the sizes of firebricks produced under normal conditions of firing. In large kilns, the bricks nearest the firemouths must, of necessity, receive more heat than those furthest away. The outward and visible symbol of the work done by the heat is the contraction. Suppose that there is a difference of two cones between the hottest and coolest parts of the burning chamber of the kiln. To fix the idea, suppose the average firing temperature of the kiln is cone 7; that in the hottest parts the firing temperature is cone 8; and in the coolest parts cone 6. Suppose the bricks made from each of the clays of the types indicated in Fig. 1 are in question. Then the stippled portion of Fig. 3 represents the variation of temperature in the firing chamber; the curves represent the contraction at different firing temperatures; and the distance apart of the cross-hatched portion represents the variations in the sizes of the resulting firebricks. In the one case the variation is 0·25 p.ct., or one-fiftieth in.; and in the other 1·55 p.ct., or one-seventh in. Otherwise expressed, deviation in the one case is ±0·12 p.ct. and in the other ±0·77 p.ct.

While the irregularities in sizes at cone 7 and upwards are within manageable proportions with clay *A*, they are not so with clay *B*. If the irregularities with clay *B* are to be kept within the same limits as with clay *A*, it would be necessary to fire clay *B* to a temperature in the vicinity of cone 14. Although I am here taking extreme cases in order to emphasize the idea, the examples selected are actually in use for the manufacture of firebricks. I say nothing about the action of the grog, or of the fortifying of the clay with siliceous materials, or of bricks whose special function is the resisting of fluxes, slags, glasses, and frits. These introduce complications in detail, without interfering with the general principle which covers all cases known to me. It is, of course, assumed that the clays are not the bloating type.

To Summarize.

(1) The maturing temperature of firebricks is not a fixed point to be decided by a specification applicable to all fireclays; rather it is a temperature peculiar to each clay.

(2) The best temperature for maturing a firebrick made from the ordinary types of fireclay is that temperature at which the contraction-temperature curve (Fig. 1) has flattened, so that any further rise of temperature produces insignificant changes in volume when the firebrick is heated to the highest temperature at which it is likely to be used.

(3) If the contraction-temperature curve (Figs. 1–3) has not flattened at the top temperature of the kiln, there will be greater variations in the sizes of the bricks than is the case where the bricks are fired at the temperature where this curve has flattened.

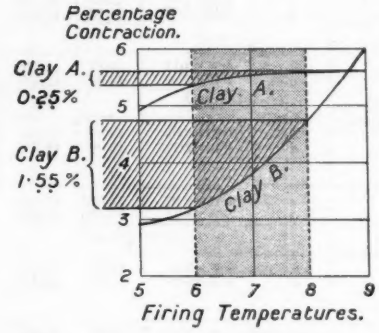


Fig. 3.—Variation in the Sizes of Firebricks from a Kiln with Two Different Types of Clay.

In adapting the above ideas to silica bricks, it must be remembered that, in ordinary firebricks, the expansion due to the contained free silica is obscured by the contraction due to the permanent contraction of the clay itself, and to the surface tension of the fluxes. With silica bricks there is a complication in that the change in size during firing is a complex, in which the contraction due to the surface tension of the fluxes is masked by the permanent expansion of the quartzose constituents. The expansion-temperature curve of silica bricks flattens only when the conversion from the high specific gravity to the low specific gravity form of silica is approaching completion.

I have said nothing about controlling the temperature of a kiln so that different parts of the kiln receive approximately the same quota of heat. One of the most important, perhaps the most important, of all the factors involved, is the setting of the bricks in the kiln. If the setting is such that the currents of flaming gases from the fire-mouths are not uniformly distributed among the bricks, then the bricks, in tracks specially favoured by these hot gases, will receive more than their share of the firing, and those in the less favoured parts will not receive an adequate ration of heat. The case is occasionally more serious than this, particularly when bricks are set too closely. The ends of the bricks exposed to the hot gases receive so much greater a proportion of heat than can be distributed uniformly through the brick by conduction, that they contract more and give the brick more or less a wedge-shape, or the brick is distorted in other ways. This may occur when the texture of the brick is homogeneous, and every condition other than the setting is satisfactory.

It is obviously a good policy to set the bricks in a kiln as closely as practicable, so as to economize as much space and keep the output as high as possible. The practical limit is the uniform and rapid distribution of heat. When a more open setting is adopted in a kiln where it has previously been too close, the decrease in the output per kiln must be balanced fairly against (1) a greater proportion of firsts and a smaller proportion of seconds and rejects for grog; (2) a probable decrease in the time required for the burning; and (3) often a marked reduction in the coal required per 1000 bricks. In the cases of two high temperature kilns, I have been astonished at the saving in time and fuel when the setting was changed from a close to an open system.

(G) THE THERMAL CONDUCTIVITY AND SOME OTHER PROPERTIES OF TWO COMMERCIAL, HEAT - INSULATING BRICKS USED IN KILN CONSTRUCTION.*

By A. T. GREEN.

Recent investigations of the thermal efficiencies of kilns have shown definitely the amount of heat lost by way of the kiln walls. Thus, Harrop[1] indicated that, with a certain continuous tunnel kiln a loss, by such causes, of some 45 p.ct. of the total fuel fired is experienced. Bleininger,[2] in an investigation of three commercial kilns, noted a loss through the walls of 25 p.ct. of the total fuel fired. A suggestion which aimed at the reduction of this loss was made in 1905 by Hutton and Beard,[3] who proposed placing a layer of highly non-conducting material between the interior firebrick lining and the exterior casing of the kiln or furnace. For such a purpose, light-weight, heat-insulating materials are now being used in increasing quantities, and are responsible for much greater thermal efficiencies in many furnace operations. Bleininger, in the above-mentioned work, estimated that 60 to 70 p.ct. of the heat lost through the walls could be prevented by the use of such methods.

Accordingly, this paper chiefly sets down the results of experiments, with two batches of commercial heat-insulating material, undertaken to determine the thermal conductivity and a few other properties of a practical significance.

The Material of Experiment.

The principal constituent of the experimental bricks is kieselguhr, which is also known by the names diatomite, diatomaceous earth, and infusorial earth. It is a light, very porous earth which consists of the silicious remains of minute organisms, together with a considerable quantity of earthy impurities. Deposits of this material are widely distributed in nature. The earths used in the bricks for the present investigations were obtained from the North of Ireland (Batch A), and from Algeria (Batch B). Good accounts of the deposits and general characteristics of diatomaceous earth are given by Goodwin,[4] Charpentier[5] and Manzella[6].

In the case of the bricks of Batch A, the earth was mixed with 15 p.ct. of cork and sawdust, then mixed and moulded by hand and fired to about 850°C. The bricks of Batch B were manufactured by mixing about 15 p.ct. of sawdust and 10 p.ct. of clay with the earth. These ingredients were mixed in an open mixer, moulded by hand, and fired to about the same temperature. Sawdust was added to maintain the high porosity of the diatomaceous earth. Other light-weight refractories used for insulation purposes are also manufactured from mixtures of clay and sawdust. In this connection, it is interesting to note that Beecher[7] has established the fact that 40 p.ct. of sawdust is the practical limit for good working with a plastic clay. The practical limit, when working with diatomaceous earth, must be a much lower percentage of sawdust.

TABLE I.

Analysis of the Experimental Bricks.

Batch	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Loss on Ignition
A	73·07%	n.d.	16·62%	5·00%	0·98%	0·33%	1·10%
B	76·70%	0·62%	13·60%	0·87%	5·66%	1·32%	0·90%

Method of Experiment.

The method of experiment has been described in a previous paper[8]. Essentially, it consists in the maintenance of an even and constant temperature on the hot face of a wall of the material from the beginning to the end of an experiment, and the accurate measurement of the rate of rise of temperature for any isothermal plane at a known distance from the hot face. From data so obtained, the diffusivity and, subsequently, the conductivity are computed. Besides the conductivity, the crushing strength, porosity, specific gravity, and refractoriness of the material were determined.

* Bulletin 5, p. 10, B.R.R.A., Dec., 1923.

Results.

TABLE II.

Mark	Temp. Range.	Mean Diffusivity in C.G.S. units.	Mean Thermal Conductivity in C.G.S. units.
A^1	511°–290°C. 647°–380°C. 766°–470°C.	0·00144 0·00156 0·00174	0·00025(5) 0·00030 0·00036
A^2	511°–180°C. 647°–244°C. 766°–308°C.	0·00151 0·00167 0·00181	0·00026 0·00030 0·00035(5)
B^1	580°–334°C. 774°–469°C. 840°–502°C.	0·00170 0·00193 0·00193	0·00030 0·00038 0·00039
B^2	580°–236°C. 774°–318°C. 840°–356°C.	0·00171 0·00190 0·00198	0·00029 0·00035 0·00039
B^3	580°–346°C. 647°–390°C. 774°–464°C. 840°–514°C.	0·00175 0·00183 0·00183 0·00194	0·00031 0·00033(5) 0·00036 0·00039
B^4	580°–238°C. 647°–272°C. 774°–324°C. 840°–360°C.	0·00177 0·00180 0·00189 0·00194	0·00030 0·00031(5) 0·00035(5) 0·00038

TABLE III.

Mark	True Sp. Gr.	App. Sp. Gr.	Percentage Porosity	Crushing Strength	Refractory Test
A	2·57	0·73	71·6	286 lbs. per sq. in.	Cone 7 (1230°C.)
B	2·61	0·69	73·5	338 lbs. per sq. in.	Cone 8 (1250° C.)

Discussion of the Results.

A_1 and A_2 represent the results obtained with one brick specimen from Batch A, by the computation of the time-temperature measurements from two isothermal planes at distances of about 5 cms. and 8 cms. respectively from the hot face. Two separate experiments with two different bricks from Batch B were realized, hence the two series B_1 and B_2, B_3 and B_4. As before, B_1 and B_3 were about 5 cms., and B_2 and B_4 about 8 cms., distant from the hot face. It will be noticed that the results agree well, although the diffusivities obtained from the 8 cms. holes are, in general, slightly higher than those obtained from the 5 cms. holes. This fact has been noted in a previous report on the conductivity of refractory materials[8].

TABLE IV.

Results obtained from previous investigations with comparable materials.

Material	Temp.	Thermal Conductivity in C.G.S. units	Authority
Kieselguhr mixed with small amount of clay and fired to 900°C. (ap.)	500°C.	0·00046	Griffiths[9]
Sil-o-Cel; an American commercial product.	300°C.	0·00017 to 0·00027	Boeck[10]
Kieselguhr (loose) ..	0°C. 100°C. 400°C.	0·000144 0·000183 0·000219	Nusselt[11]
Kieselguhr (baked)	0°C. 400°C.	0·000178 0·000333	Nusselt[11]

Table IV. is included for purposes of comparison. The results obtained by Griffiths[9] are somewhat higher than those given in Table II. Boeck[10], reporting the properties of Sil-O-Cel, a comparable material, gave 0·5–0·9 B.Th.U. per sq. ft. per hour per degree Fahr. difference in temperature, between ordinary temperatures and 1000° Fahr. These values correspond to a conductivity of 0·00017–0·00027 C.G.S. units at about 300° C. Such data are slightly lower than those obtained by the present author, which agree well,

however, with Nusselt's results. Again, comparing the data given in this paper with those recently obtained by the author for the conductivity of a Stourbridge fireclay brick, it may be pointed out that the conductivity of the insulating materials A and B is about one-fourth that of this firebrick at a temperature of about 500° C.

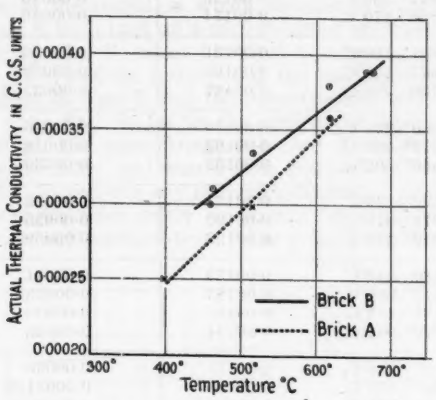


Fig. 1.—Variations of Actual Thermal Conductivity with Temperature.

The refractoriness of both materials A and B is very low. Moreover, with material A there is a very defined shrinkage commencing at 900° C. The action indicated by this shrinkage results in a great increase in the conductivity of the material. Thus, after heating the face of the brick for 20 hours at about 1120° C., the conductivity, calculated from the temperature readings of a hole 5 cms. from the hot face, becomes 0·00061 between 896 and 627° C. This shrinkage is obviously due to an incipient fusion resulting from the presence of fusible impurities. When the material is required for very high temperature insulation, some purification of the original earth should be adopted, if possible, so that a brick containing at least 92 p.ct. of silica results. In practice, however, the hot face of the insulating material does not, usually, exceed 800°C., so that many impure diatomaceous earths can be used efficiently. In this connection it must be noted that in modern kiln construction the use of insulating material is resulting in the design of thinner kiln walls. This emphasizes the fact that, wherever the walls are so designed, diatomaceous bricks of good quality must be used, since the face temperature of the insulation wall will, in these circumstances, be much higher.

It is very desirable to maintain an unimpaired wall of insulating brick covering the outer surface of the kiln walls. To do this, the insulating material must possess a good mechanical strength, since the expansion and contraction of the kiln walls give rise to very considerable strains, which are exerted on the insulation wall. Boeck states that a crushing strength of 400 lbs. per sq. inch is a very satisfactory indication of the required mechanical strength. From the nature of the material—*i.e.*, the high porosity which must be maintained in manufacture, &c.—a crushing strength much higher than 400 lbs. per sq. inch cannot be expected.

The great insulating properties of the material are due to the presence of an infinite number of minute pores which are encompassed in the organic remains of the diatomite. In fact, the structure can be conveniently regarded as an air space divided into an infinity of air cells by a minimum of solid matter. Physical reasoning indicates that the heat transmission by radiation and convection across this air space is considerably lessened in consequence of this peculiar structure. The limit of the effect of this division of the air space must be reached when the heat transmission across the pore spaces approximates in quantity almost to the likely value for the conductivity of air. The conductivity of air is given as 0·000058 C.G.S. units at 55°C., and although no data are given for this constant at higher temperatures, it is probable that the value will be at least one-twelfth the conductivity of the solid material at, say, 500° C. At lower temperatures and with a maximum of pore spaces of minute size, the transmission of heat by way of these pore spaces may, indeed, approximate to an air conduction. Such an explanation appears to cover the insulating properties of diatomaceous earth. However, a similar reasoning should not be followed too closely in the case of grogged fireclay bricks where the pores—some of them, at least—are by no means microscopic, and the temperatures of practice, to which they are subjected, are much higher.

Finally, porosity or apparent specific gravity may be used as a rough guide to the insulating properties of diatomaceous earth bricks. A brick with a percentage porosity of 70 to 80 p.ct., or an apparent specific gravity of 0·55 to 0·7, will, in general, be a satisfactory insulator.

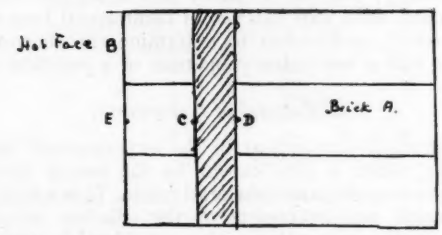
SUPPLEMENTARY TO THE REPORT OF THE RESEARCH.

The Insulating Capacity of Diatomaceous Earth.

The following experiment will serve to supplement the data of thermal conductivity. It is based on the suggestion of Hutton and Beard.

As in the experimental determination of thermal conductivity, a wall of nine bricks was erected with a central brick A as test brick (Fig. 2). Thermocouples were placed

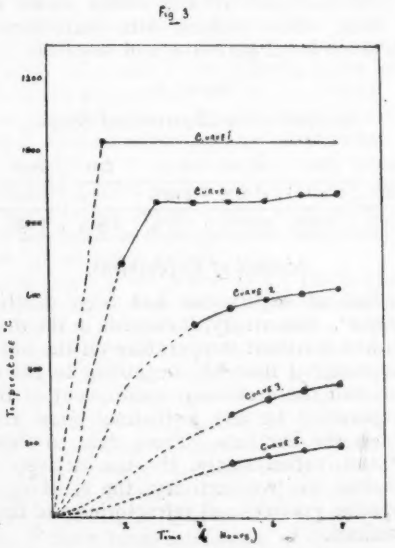
Fig 2.



in the interior of Brick A, at C and D, by way of holes which had been drilled. C was placed at a distance of 6 cms. from the hot face B, and D was 5·1 cms. (2 in.) from C. The face B was raised to a constant temperature (*i.e.*, 1037° C, 1153° C., and 1270° C.) in about 1½ hours, and maintained at this temperature for about 8 hours. This face temperature was measured by a thermocouple E luted to the centre of the face of brick A. The rate of rise of temperature at the isothermal planes, represented by vertical planes C and D, was measured over a period of the experiment. The results are shown in Figs. 3, 4, and 5. Curve 1 in each diagram shows the face temperature, and curves 2 and 3 the rate of rise of temperature at the isothermal planes C and D respectively. These curves can be regarded as the basis of comparison in indicating the effect of diatomaceous earth.

The bricks were next sawn through at the planes represented by C and D. They were fitted in the structure so that the space between the planes at C and D was filled

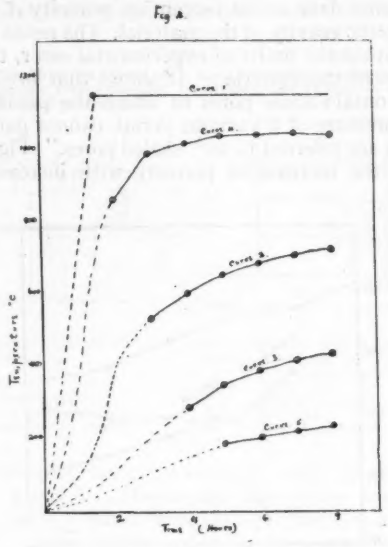
Fig 3

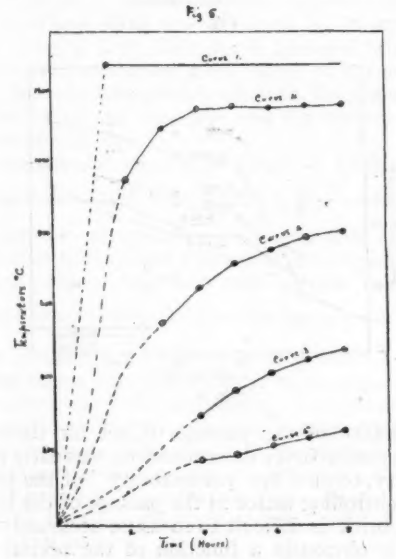


with very pure diatomaceous earth "flour" tamped to a consistency of 22 lbs. per c.ft. (*i.e.*, of an apparent

specfiic gravity of 0·35 grms. per c.c.). The determination of the rate of rise of temperature at the planes C and D (the positions of which were exactly the same as in the first series of experiments) was conducted on lines identical with those mentioned above.

The results are shown in Figs. 3, 4, and 5. Curves 4 and 5 represent the rate of rise of temperature at planes C and D respectively, when the diatomaceous earth is packed to a





consistency of 22 lbs. per c.ft. Such curves effectively illustrate the insulating capacity of the material of experiment.

An approximate calculation based on Figs. 3, 4, and 5 shows that, considering the equilibrium amount of heat passing through the brick (without the interposition of diatomaceous earth) as unity, the amount of heat passing through when diatomaceous earth is interposed as a layer 2 in. thick, and at a consistency of 22 lbs. per c.ft., is 0·333.

The author wishes to thank the Derbyshire Silica Firebrick Co. for the help and privileges they have extended in connection with this investigation, and Mr. H. Edwards for his very able assistance.

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(*H*) THE INFLUENCE OF TEXTURE ON THE TRANSMISSION OF HEAT THROUGH FIREBRICKS.*

A. T. GREEN.

INTRODUCTION.

The transmission of heat through firebricks takes place by way of both the solid matter and the pores. It has been stated that the transference of heat through the pores is very small compared with that transmitted through the solid matter, or, in other words, pore-spaces consistently maintain insulating properties. It would thus follow that the higher the porosity of a refractory material, the greater ought its insulating effect to be. This argument appears to be justified by the fact that such highly porous materials as diatomaceous earth bricks possess pronounced insulating properties at lower temperatures[1] (*i.e.*, up to 700°C.), and thus under the accepted conditions of their use. However, some investigators, notably Mellor[2], have, as the result of practical observation and of theoretical deductions, suggested the hypothesis that, at high temperatures, heat may be transmitted by way of the pores, at a rate which is comparable with that of conduction through the solid matter. In an earlier work[3] by the present author, two facts seemed to bear out this hypothesis. In the first place, the pronounced rate of increase in the value of the coefficient of thermal conductivity of some bricks with temperature, at temperatures above 1000° C., was suggestive of influences additional to the conduction of heat through the solid matter. Again, a calculation based on the fourth-power radiation law, and the data obtained from the determinations of thermal conductivity, showed that the rate of heat transmission by radiation across the pore-spaces may be, at temperatures over 1100°C. at least, comparable with the rate of heat conduction through the solid matter.

In the paper mentioned above, it was pointed out that the essential factors governing the effect of the pore-spaces appeared to be (1) the temperature; (2) the size of the pores; (3) their disposition with respect to the solid matter. In other words, it can be stated that previous work has suggested the view that the rate of heat transmission through certain refractory materials is dependent, in some degree, on the temperature and texture of the material. The present work was commenced with the object of testing this suggestion.

MATERIALS OF EXPERIMENT.

The Making.—The difficulty of obtaining firebrick identical in composition and constitution—*i.e.*, of identical "material factor"—and yet possessing different texturess is very great. This fact will be noted in the study of the properties of the different classes of bricks used in this investigation. However, with the object of confining this "material factor" to a narrow range of variation, all the bricks were made from one batch of Stourbridge fireclay. The grog used was made from the same clay, at a particular firing. This grog was divided into three grades, *i.e.*, (1) that which passed through a $\frac{1}{5}$'s lawn; (2) that which passed through an $\frac{1}{8}$'s lawn and stayed on a $\frac{1}{10}$'s lawn; (3) that which passed through a $\frac{1}{4}$'s lawn and stayed on an $\frac{1}{8}$'s lawn. The bricks were made up of the following mixtures:

TABLE I.

BATCH. I.

Grog passes through $\frac{1}{10}$'s lawn.

Mark	*A*	*B*	*C*	*D*	*E*	*F*
Clay (parts by weight) ..	10	9	8	7	6	5
Grog (parts by weight) ..	0	1	2	3	4	5

* Bulletin 6, p. 47, B.R.R.A., April, 1924.

BATCH II.

Grog passed through ¼'s lawn and stayed on ⅛'s lawn.

Mark	G	H	I	J	K
Clay (parts by weight) ..	9	8	7	6	5
Grog (parts by weight) ..	1	2	3	4	5

BATCH III.

Grog passed through ¼'s lawn and stayed on ⅛'s lawn.

Mark	L	M	N	O	P
Clay (parts by weight) ..	9	8	7	6	5
Grog (parts by weight) ..	1	2	3	4	5

Each of the above mixtures was assembled and prepared by hand, and, after allowing to stand for a short time, was slop moulded. Twelve bricks of each mark were made. They were then fired to Cone 10. The analysis of a fired brick *F* showed SiO_2, 69·94%; Al_2O_3, 23·50; Fe_2O_3%, 1·75%; TiO_2, 1·27%.

The Properties.—The investigated properties of all the bricks are appended in Table II.

TABLE II.

Mark	P.Ct Porosity *A*.	P.C. Porosity *B*.	Diff. between *B* & *A*.	True Sp. Gr.	App. Sp. Gr.	Crushing Strength in lbs./sq. inch
			Batch No. 1.			
A	22·04	25·65	3·61	2·631	1·956	5080
B	22·75	25·92	3·17	2·627	1·946	5434
C	26·91	27·72	0·81	2·626	1·898	4244
D	27·21	27·92	0·71	2·622	1·890	4055
E	27·91	28·19	0·28	2·618	1·880	3141
F	28·32	28·52	0·20	2·616	1·870	2325
			Batch No. 2.			
G	23·21	25·41	2·20	2·617	1·952	3358
H	24·62	25·26	0·64	2·609	1·950	2810
I	24·68	25·70	1·02	2·607	1·937	2155
J	25·32	26·47	1·15	2·604	1·914	2092
K	26·33	27·14	0·81	2·601	1·895	1296
			Batch No. 3			
L	24·05	25·54	1·49	2·623	1·952	3822
M	25·20	26·00	0·80	2·615	1·935	2729
N	25·00	26·00	1·00	2·610	1·931	1646
O	25·75	26·40	0·65	2·610	1·921	1264
P	25·91	26·88	0·91	2·612	1·910	1132

The instructions to the manufacturer stated that the burning should be identical for all batches. However, some variation in this burning appears to have occurred, since the average true specific gravity of Batch I. is 2·622, of Batch II. 2·607, and of Batch III. 2·614. The specific gravity determinations, on which the figures are based, were obtained by the use of specific gravity bottles. Special precautions, including (1) the use of paraffin as the liquid; (2) the use of a vacuum pump; and (3) the use of a thermostat, were taken, and, as a result of these, an error of not more than 0·005 for each determination is anticipated. Two determinations were made for each brick and the average taken. It is considered probable that a difference of two cones in the firing will cause the variation from 2·622 to 2·607 noted in the average specific gravity. The decrease in the true specific gravity with increasing grog content is a feature of each batch, and lends additional proof to the suggestion that Batch II. has received more "fire" than Batch III., which, in turn, has received more fire than Batch I. (See Fig. 1.)

The percentage porosities (*A*) were determined by the usual method, from the data (1) weight of a piece of dry brick; (2) weight when soaked in paraffin; (3) weight when suspended in paraffin. The average of four of the most concordant of six determinations was taken. The determinations do not show a wide range of porosity, although actually other factors must be considered. With each of the bricks *A*, *B*, *G*, and *L* the presence of large holes interspersed throughout the semi-vitrified mass was very marked. In fact, the porosity determinations on this account were very variable. These holes were noticed in at least half the pieces of bricks used for the determinations. This suggests that the porosities *A* reported for the bricks *A*, *B*, *G*, and *L* are composed of at least two types (1) large holes due to the nature of the clay, the nature of the making process, and the insufficiency of grog of the correct grade, (2) the finer pores running through the semi-vitrified mass. In bricks *A*, *B*, *G*, and *L*, another type of pore must be considered. The existence of this kind is suggested by the percentage porosity *B*. This determination is computed from (1) the apparent specific gravity which is obtained from the same data as the percentage porosity *A*; and (2) the true specific gravity of the material. The result obtained includes, within the limits of experimental error, the whole of the pores of the material. It shows that bricks *A*, *B*, *G*, and *L* contain some pores to which the paraffin, even under the pressure of a vacuum pump, cannot gain access. These pores are referred to as "sealed pores." Fig. 2 shows graphically the increase in porosity with increasing grog content.

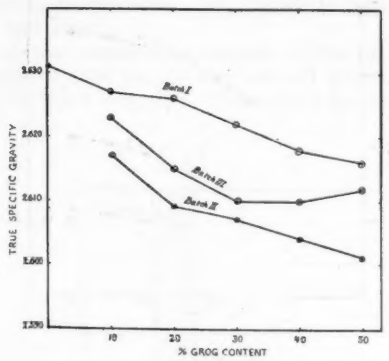


Fig. 1.

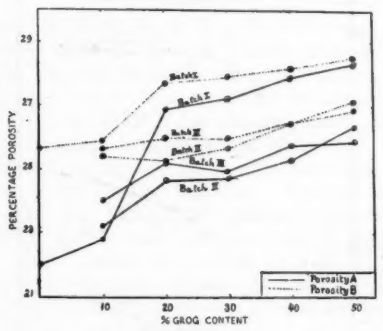


Fig. 2.

The possibility of the passage of hot air through the brick during conductivity determinations was early realized. That property, termed the "permeability" of the material, which is a controlling factor in the passage of the hot gases through the brick, is difficult to measure accurately. Such a property is obviously a function of the texture of the material, and consequently it was thought that a knowledge of the crushing strength together with the porosity of the material would give some idea of the permeability of the material under experiment. For this reason the crushing strength determinations are appended in Table I. and graphed in Fig. 3.

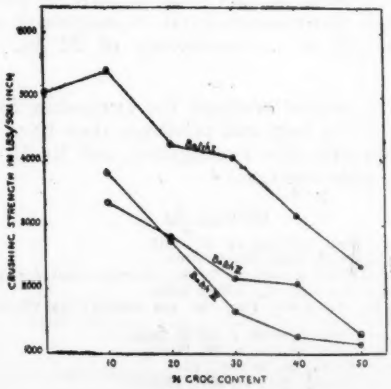


Fig. 3.

DETERMINATION OF THE THERMAL CONDUCTIVITY.

The method adopted for the determination of the coefficient of thermal conductivity has been fully described in a previous publication.[3] The following *résumé* of the description is added in order to make an interpretation of the results more clear. First, the procedure consists in maintaining an even and constant temperature on the hot face of a wall composed of nine bricks of the material under test, from the beginning to the end of the experiment. An electric furnace based on the principle of the Hirsch refractory testing furnace is used for this purpose (see Figs. 4 and 5). The second part of the work consists in measuring at fixed intervals of time—usually every hour—the temperatures of two isothermal planes at distances of about 5 cms. and 8 cms. respectively from the hot face. These data are obtained by thermcoouples, secured in holes of $\frac{3}{16}$ in. diameter in a central brick. When the couples are in position, these holes, which are parallel to the hot face, are filled with brick dust. Such temperatures are referred to as the first-hole and the second-hole temperatures respectively.

Fig. 4.
Cross-Section through Plane of Thermo-Couple Holes parallel to the Base of Apparatus.

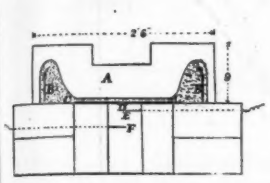
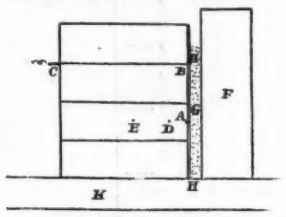


Fig. 5.
Cross-Section perpendicular to the Plane of the Thermo-Couple Holes.



A, furnace part of refractory clay.
B B, electrodes.
C C, hot plate.
D, face thermo-couple.
E, 1st hole thermo-copule.
F, 2nd hole thermo-couple.
A D E, position of three thermo-couples
A B C, shows the path of the face of thermo-couple.
F, furnace part.
G, graphite resister.
H H, hot plate.
K, base of apparatus.

This experimental method is based on Fourier's law of linear diffusion. Thus, by evaluating $\frac{\theta_0 - \theta}{\theta_0 - \theta'}$, where θ_0 is the constant hot-face temperature and the hole temperature after a specific time (about 7·5 hours) has elapsed, a factor is obtained which, together with certain mathematical tables, defines a numerical value for the expression $\frac{x}{2\sqrt{kt}}$.

Since x is the distance of the hole from the hot face and t is the time which has elapsed from the commencement of the experiment until the temperature θ is obtained at this hole, k, which is the diffusivity or "temperature conductivity" of the material can be readily obtained. The value of k so obtained is the average value between the temperature limits θ_0 and θ. To calculate the coefficient of thermal conductivity between the temperature limits θ_0 and θ we have the equation

$$\text{Thermal conductivity} = k.c.s.$$

where k is the determined diffusivity, c is the apparent specific gravity of the material and s is the specific heat of the material between the two temperature limits θ_0 and θ. The product $c.s.$ is thus the heat capacity per unit volume.

RESULTS.

The results of the thermal conductivity experiments are appended in Tables III. and IV.

TABLE III.

Conductivity Results for Brick A.

1st Hole Determinations.				2nd Hole Determinations.			
Temp. Range	Temp. Range No.	Mean Diffusivity in C.G.S. units	Mean Thermal Conductivity in C.G.S. units	Temp. Range	Temp. Range No.	Mean Diffusivity in C.G.S. units	Mean Thermal Conductivity in C.G.S. units
920°-612°C.	(1)	0·00259	0·001155	920°-480°C.	(1)	0·00266	0·00153
1037°-697°C.	(2)	0·00265	0·00163	1037°-547°C.	(2)	0·00270	0·00161
1153°-786°C.	(3)	0·00275	0·00175	1153°-615°C.	(3)	0·00278	0·00171
1270°-870°C.	(4)	0·00282	0·00184	1270°-687°C.	(4)	0·00281	0·00179

TABLE IV. Batch I.

	1st Hole Determinations			2nd Hole Determinations.	
Mark	Temp. Range No.	Mean Diffusivity in C.G.S. Units	Mean Thermal Conductivity in C.G.S. Units	Mean Diffusivity in C.G.S. Units	Mean Thermal Conductivity in C.G.S. Units
B	(1)	—	—	—	—
	(2)	0·00262	0·00161	0·00275	0·00163
	(3)	0·00275	0·00174	0·00282	0·00174
	(4)	0·00280	0·00183	0·00290	0·00183
C	(1)	0·00249	0·00144	0·00253	0·00140
	(2)	0·00259	0·00154	0·00270	0·00155
	(3)	0·00271	0·00167	0·00277	0·00166
	(4)	0·00282	0·00179	0·00294	0·00182
D	(1)	0·00234	0·00134	0·00235	0·00129
	(2)	—	—	—	—
	(3)	0·00260	0·00160	0·00272	0·00161
	(4)	0·00275	0·00174	0·00290	0·00178
E	(1)	0·00240	0·00137	0·00242	0·00133
	(2)	0·00253	0·00149	0·00272	0·00152
	(3)	0·00267	0·00163	0·00286	0·00169
	(4)	0·00286	0·00180	0·00298	0·00184
F	(1)	0·00233	0·00132	0·00235	0·00128
	(2)	0·00256	0·00151	0·00259	0·00148
	(3)	0·00282	0·00171	0·00299	0·00176
	(4)	0·00310	0·00194	0·00307	0·00186
Batch II.					
G	(1)	0·00268	0·00159	0·00268	0·00153
	(2)	0·00284	0·00174	0·00280	0·00167
	(3)	0·00299	0·00190	0·00298	0·00183
	(4)	0·00310	0·00203	0·00308	0·00195
H	(1)	0·00268	0·00159	0·00272	0·00155
	(2)	0·00280	0·00172	0·00286	0·00170
	(3)	0·00294	0·00186	0·00293	0·00181
	(4)	0·00308	0·00201	0·00308	0·00194
I	(1)	—	—	—	—
	(2)	0·00269	0·00163	0·00261	0·00154
	(3)	0·00282	0·00173	0·00276	0·00165
	(4)	0·00305	0·00195	0·00298	0·00185
J	(1)	0·00252	0·00147	0·00260	0·00146
	(2)	0·00266	0·00162	0·00270	0·00158
	(3)	0·00289	0·00180	0·00284	0·00171
	(4)	0·00306	0·00196	0·00308	0·00192
K	(1)	0·00246	0·00142	0·00268	0·00149
	(2)	0·00259	0·00155	0·00270	0·00156
	(3)	0·00280	0·00171	0·00295	0·00176
	(4)	0·00300	0·00190	0·00310	0·00191
Batch III.					
L	(1)	0·00259	0·00154	0·00272	0·00156
	(2)	0·00267	0·00164	0·00280	0·00167
	(3)	0·00282	0·00179	0·00290	0·00178
	(4)	0·00295	0·00194	0·00304	0·00193
M	(1)	0·00255	0·00150	0·00268	0·00152
	(2)	0·00270	0·00165	0·00274	0·00162
	(3)	0·00280	0·00176	0·00283	0·00173
	(4)	0·00297	0·00193	0·00299	0·00188
N	(1)	0·00253	0·00149	0·00270	0·00153
	(2)	0·00264	0·00161	0·00283	0·00166
	(3)	0·00278	0·00174	0·00295	0·00178
	(4)	0·00292	0·00189	0·00300	0·00188
O	(1)	—	—	—	—
	(2)	0·00258	0·00157	0·00265	0·00155
	(3)	0·00280	0·00175	0·00290	0·00175
	(4)	0·00306	0·00197	0·00308	0·00192
P	(1)	0·00248	0·00144	0·00266	0·00150
	(2)	0·00254	0·00153	0·00276	0·00161
	(3)	0·00272	0·00169	0·00290	0·00174
	(4)	0·00293	0·00188	0·00302	0·00188

The hot face temperatures used in the majority of the experiments were 920° C., 1037° C., 1153° C., and 1270° C. These temperatures, which may appear a peculiar selection, were occasioned by the fact that the face thermocouple and the galvanometer were not made for each other. Consequently, although easily controllable temperatures were used, the above temperatures resulted from the standardization of this couple and the galvanometer against substances of known melting points, and against a standard thermocouple. If the face temperature used was different from those mentioned above, a computation served to bring it to the same basis. For brick *A*, the temperature ranges are given, but, since the variation of the hole temperatures was rarely more than 25° C. from an average for the particular range, it was considered that the categories, temperature ranges Nos. (1), (2), (3), and (4) would suffice to indicate the respective ranges, without introducing any appreciable error. The time factor averaged about 7·4 hours, while the distance factor varied from 4·7 to 5·4 cms. in the case of the first hole, and from 7·7 to 8·3 cms. in the case of the second hole.

Since the temperature of the second hole is lower than that of the first, the results obtained for the second hole should be correspondingly lower. As a matter of experiment, the diffusivity measurements are inclined to be higher, a fact noted in previous work on the subject. The

argument that the first hole somewhat disturbs the flow of heat, with a consequent effect on the second hole temperature, has already been put forward. The function of the second hole result, however, is merely to check that obtained from the first hole.

DISCUSSION OF RESULTS.

Comparison of Batches.—A general consideration of the results of the three batches points definitely to the fact

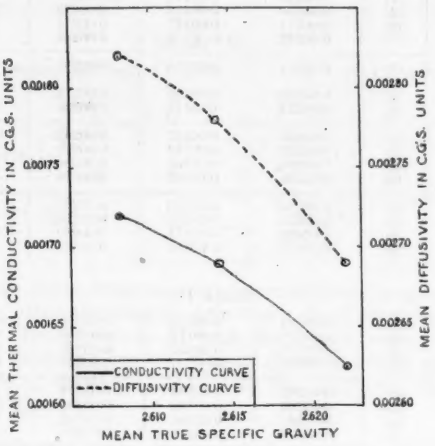


Fig. 6

that Batch II. possesses the highest average conductivity. Batch III. comes next, with Batch I. possessing the lowest average value of this "constant." It has been previously noted that the average specific gravities follow the reverse order with Batch II. possessing the least value. This was taken as an indication that Batch II. had received the most "fire," and Batch I. the least. It is thus suggested that, the greater the "fire," the higher the value of the thermal conductivity. This fact has been previously brought forward by Wologdine[4], and others. Fig. 6 shows graphically the relation between average specific gravity and the average thermal conductivity.

It must be mentioned that the above facts vitiate a direct and uncompromising comparison between the three batches, *i.e.*, between the effect of different sizes of grog, since the exact quantitative effect of this suggested variation in firing on the value of the coefficient of thermal conductivity is not known. However, the fact that there is only 0·00010 C.G.S. units (*i.e.*, about 6 p.ct.) difference between the average conductivity of Batch II. and Batch I. indicates that the size of the grog in our experimental bricks does not have a very pronounced effect except in so far as this size controls the porosity and permeability.

The Effect of Porosity.—It is obvious from the meaning of percentage porosity that, if the true specific gravity of the material remains constant in any set of firebricks, the apparent specific gravity must decrease with increasing porosity. Now, since the product of the coefficient of diffusivity, the apparent specific gravity, and the specific heat—which from a consideration of previous work on this constant must be approximately the same in its values at different temperatures for all the experimental materials—gives the coefficient of thermal conductivity, it follows that, in order that the conductivity shall remain constant when the porosity increases, the diffusivity must increase with increasing porosity in an exactly reciprocal manner, *i.e.*, the result should show that the product of the diffusivity and apparent specific gravity is a constant. Generally, the experimental data, up to temperatures of 1000° C., do not show that diffusivity increases with increasing porosity in the manner defined, with the consequence—particularly at low temperatures—that the thermal conductivity decreases with increasing porosity. This is well illustrated in the previous report on the conductivity of diatomaceous earth bricks in which it was shown that although the diffusivity of this material is only about 20 p.ct. less than the diffusivity of firebrick, the conductivity is but one-third to one-fourth that of the same material. This is made evident by the fact that the apparent specific gravity of diatomaceous earth material is about two-fifths that of firebrick, and that the porosity is three-and-a-half times greater. Thus in general, diffusivity measurements at lower temperatures indicate that with increasing porosity decreasing thermal conductivity is to be expected.

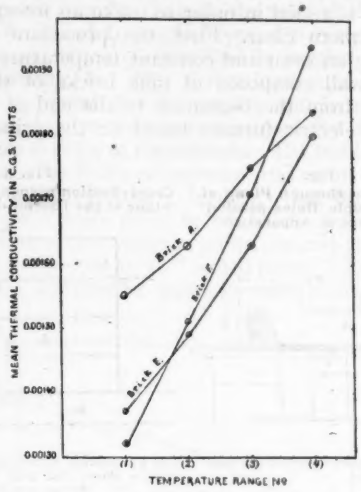


Fig. 7.

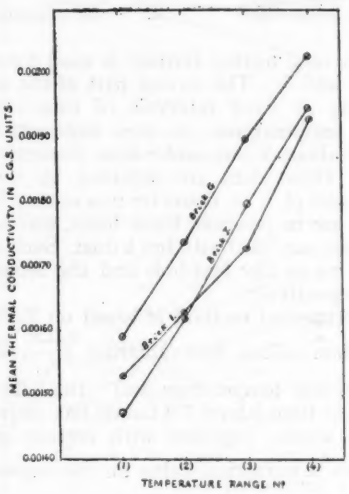


Fig. 8.

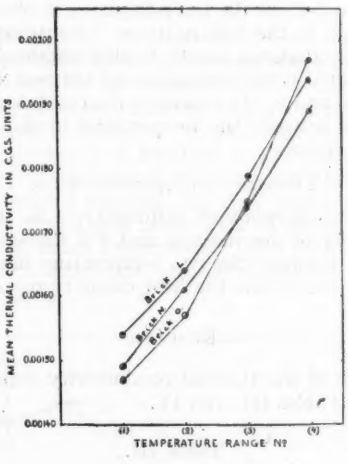


Fig. 9.

Compare now the reported values of brick *B* and brick *F*, of brick *L* and brick *O*. In each case the material with the higher grog content has a lower diffusivity and thermal conductivity for temperature range No. (1) than the lower grog material, while at the highest temperature range No. (4) the reverse is the case. This is well shown in Figs. 7 and 9. Thus the fact that the material with a high-grog content has a greater rate of increase of conductivity and diffusivity than the low-grog material is well indicated.

Fig. 8 for Batch II. material shows the rate of increase of thermal conductivity with temperature, and, although the rate of increase is not so pronounced as in the other two batches, it is quite evident. With the object of showing more clearly this more rapid rate of increase with increasing grog content, Fig. 10 is added. In this graph the difference

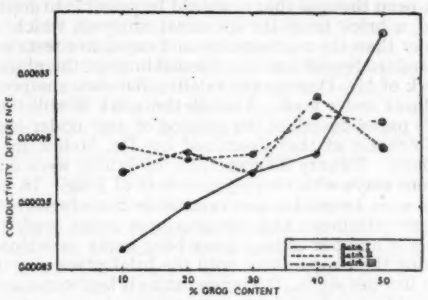


Fig. 10.

between the conductivities reported for temperature ranges (1) and (4) is plotted against percentage grog content. For all batches there is shown a tendency towards the greater rate of increase of conductivity with increasing grog content. Batch I. indicates this in a decided manner. In fact, it is felt that the conductivity results reported for brick *F* are slightly too high at the higher temperatures.

Consider Figs. 11 and 12. The former represents the average of the conductivities of temperature ranges (1) and (2), for each mark plotted against grog content, and the latter the average of temperature ranges (3) and (4) similarly plotted. The general interpretation of these two curves is similar to the one given for Fig. 10; the decrease in the conductivity with increasing grog content being more pronounced in the case of low-temperature determinations than in the case of high-temperature determinations. Fig. 12 shows the peculiar behaviour of the bricks in Batch I. at high temperatures, in which the conductivity apparently reaches a minimum at 30 p.ct. grog content. Since this

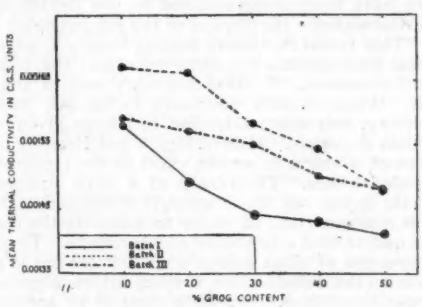


Fig. 11.

does not altogether agree with what is noted in the case of the other two batches, it is suggested that there is possibly some mal-observation in this result. In fact, in the case of Batch I. the decrease in conductivity from 10 to 30 p.ct.

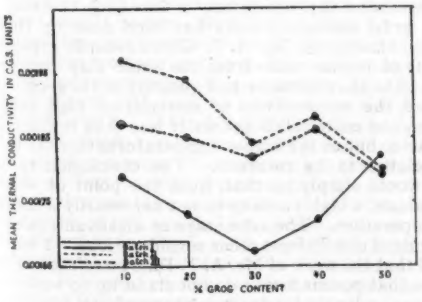


Fig. 12.

grog and the increase from 30 to 50 p.ct. grog seems to be too great to be accounted for by the theory which follows. With allowances, however, this curve is amenable to a general consideration.

A Suggested Explanation.

A study of the results indicates one of two facts, either (1) that the high grog content material, which, of course, possesses a higher porosity, has, at the high temperature of the experiment, a higher diffusivity and thermal conductivity than the low-grog material, or (2) that at somewhat higher temperatures than those of the experiment, the higher grog content material will have a higher thermal conductivity and diffusivity than that of the low-grog material.

These indications are the results of the addition of grog to the clay. In other words, either the grog of itself, or the effect of the grog on the texture of the brick, causes this increase in the values of the conductivity and diffusivity. If the grog of itself, because it has received extra heat treatment and, therefore, possesses a higher thermal conductivity, is the cause, then it must be expected that the conductivity of high-grog material at low temperatures must be higher than the conductivity of low-grog material at the same temperatures. This is by no means the case; the conductivity of the high-grog material being, in practically all cases, lower than the conductivity of low-grog materials at low temperatures. Thus for temperature range (1) the conductivity of brick *A* is 0·00155, but for brick *F* it is 0·00132; for brick *L* with the same temperature range it is 0·00154; for brick *P* it is 0·00144. It may thus be argued with confidence that the effect of the grog of itself is not the cause of the observed comparatively higher conductivity values of the high-grog materials at high temperatures.

The effect, then, is concerned obviously with the alteration of the texture of the materials by the grog, and further, with some noticeable alteration in the behaviour of the pore spaces. Thus the conclusion is reached that heat is transmitted, in appreciable quantities, by way of the pores. Such a transmission can consist of one or both of two phenomena, *i.e.*, radiation and convection. Considering the former, the calculation mentioned in the introduction, and put forward in a previous paper[3], showed that pore spaces less than 0·005 cms. across in the direction of the heat flow had a practically negligible effect. However, with such pores of greater width than 0·02 cms., the probability of an effective heat transmission by radiation at temperatures over, say, 1150° C. is very pronounced. The materials under investigation—particularly those containing the higher grog contents—could be seen actually to possess many elongated pores, situated in such a manner as to be almost in the direction of the heat flow in the experiments. In this investigation, the observed rapid increase in the thermal conductivity of the high-grog material is in part probably due, then, to a radiation effect.

Convection effects are also likely to occur. The extent of such effects will be dependent, in no small measure, on the relative permeability of the material to gases. This property is somewhat connected with porosity, in so much as the distinguishing feature of permeability is a continuity of pore, allowing a direct, and, more or less, unimpeded passage for gases. Permeability thus depends on the number of channels or connected pores, which enable the permeating fluid to pass through. The following figures, reported by Queneau, illustrate the distinction between porosity and permeability.

Material	Percentage Porosity	Relative Permeability
Firebrick	30·85	14·7
Firebrick	30·20	106·2

It is thus easy to conceive of great differences in the permeabilities of the high-grog bricks of our experiments as compared with the low-grog bricks. The percentage porosities, however, do not differ by 5 p.ct.

Considering a brick of relatively high permeability, first we see that, under the conditions of our experiment, the air in the pores at the hot-face end becomes highly heated, and, of a consequence, possesses a decided mobility. This gives rise to convection currents within the pores of the brick, which currents have a greater range of effect in the case of a material of greater permeability. In its transit

this air gives heat to the solid particles, increasing their temperatures above that value which would result from pure conduction through the solid matter. Such heat gain and heat loss by convection is proportional to T^n, where T is the difference in temperature between the heating gas and the surface of the particle being heated, and n is an index probably greater than 1. For heat losses by natural convection at low temperature, $n=1{\cdot}25$ (Griffiths)[6], but there is reason to believe from the work of Langmuir that n for convective losses approximates to 1·6 as the temperature reaches over 1450° C. Little or no reliable data circumscribing the actual transference of heat from a gas at a high temperature (over 1000° C.) to a surface have been published, but theory points to an enhanced convective heating at high temperature.

The net result of the convective effect of hot air in the pores of the brickwork must be that the temperature at different points in the brick will be raised, with a consequent effect on the temperature gradients. Under the conditions of the above experiment, an approximate equilibrium will be reached between the hot air and the hot solid matter, after a certain time has elapsed. Since the rate of rise of temperature at the first hole is rarely more than 12° C. per hour after a time of eight hours from the commencement, it is thought that, at this period, a sufficiently approximate equilibrium has been established at this isothermal plane.

Howe and Phelps[8] have thrown some light on the quantitative effect of heating by convection, when the hot gases are drawn through brickwork under pressure. Although their results cannot be directly introduced into the above argument, they indicate the effect of hot gases on the temperature gradients in firebricks. A selection of the reported results of these investigations is appended in Table V.

TABLE V.

Furnace Temp.	1340° C.	1340° C.	1340° C.	1220° C.	1220° C.
Pressure of Furnace Gases.. (inches of water)	+ 1·00	+0·05	− 0·30	+ 0·95	+ 0·05
Temp. of firebrick ½" from hot face	1305° C.	1265° C.	1105° C.	1105° C.	1075° C.
Temp. of firebrick 1" from hot face	1270° C.	1210° C.	1020° C.	1135° C.	965° C.
Temp. of firebrick 2" from hot face	1125° C.	1040° C.	800° C.	900° C.	770° C.
Temp. of firebrick 3" from hot face	1040° C.	950° C.	720° C.	800° C.	660° C.

It appears, therefore, that convection plays an important part in heat transmission through relatively permeable firebricks.

The passage of heat by conduction is affected by the degree of continuity of solid matter existing in the material. It is obvious, then, that the semi-vitrified nature of bricks *A*, *B*, *G*, and *L* gives them a power for pure conduction greater than those which have had this continuity interrupted by grog. Thus, when the transmission of heat is in the main the result of pure conduction, *i.e.*, at low temperatures, such a low-grogged material will show a higher determined coefficient of thermal conductivity. This is in accordance with the results (*vide* Figs. 7, 8, and 9). However, the rate of increase of heat transference by conduction with temperature does not appear to be so great as the rate of increase in the transmission of heat by convection and radiation in the pore-spaces, with the result that the two latter effects overtake in value the conductive effects. This, therefore, accounts for the more rapid increase with temperature in the observed value for the coefficient of thermal conductivity of the high-grog bricks at high temperatures.

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Discussion.

The PRESIDENT: I propose to ask Mr. Leather, in the absence of Mr. Broadberry, to introduce the Refractory Materials Report, and then the discussion on Mr. Emery's paper and the report can ensue.

Mr. LEATHER, introducing the report, said: I regret that Mr. Broadberry is not able to be here to present this report. Though a great deal of the work is now done by the British Refractory Research Association, with the assistance of the Privy Council Committee, the Institution being represented on the Association, much more research is still needed to produce results in the form of goods capable of enduring the high temperatures towards which practice constantly tends. However, it is satisfactory that the Association now appear to have surmounted the initial difficulties of organization and to be getting into more effective work. It has often been thought that it should be possible to determine the quality of a brick from the chemical analysis, which would be much easier than the cumbersome and expensive tests prescribed in our Standard Specification. Special interest therefore attaches to the work of Mr. Dale on the relation between composition and refractoriness under load. Though the work is still incomplete, Mr. Dale's paper describes the method of test under load, which is a modification of that described by Dr. Mellor in the 1918 Transactions. Twenty different sets of bricks were made from five different clays with varying amounts of grog. In each case the bricks were tested for contraction in manufacture, porosity, ordinary refractoriness, and refractoriness under load. In addition to this, a number of tests have been made in which, instead of increasing the temperature until the brick gives way under the load of 50 lbs. per sq. in., the temperature is kept constant at 1350° C. The yielding of firebrick is not an instantaneous phenomenon occurring at a definite temperature, but if time is given may take place at a much lower temperature. A piece of sealing wax supported at the ends will bend under its own weight at the ordinary summer temperature if given plenty of time, while to bend the same amount more quickly would require a much higher temperature. Fig. 11 in Mr. Dale's report shows the results with one kind of clay. The first portion of the curves indicate the expansion as the temperature rises to about 1200° C. After this, with prolonged heating at 1350° C., the brick yields slowly under the load; the striking thing being that the bricks with 40 p.ct. and 60 p.ct. of grog give way much more rapidly and completely than the straight clay and the one with 20 p.ct. of grog. Further results with other clays will be published later. Until the tests are complete, it is perhaps dangerous to draw definite conclusions. It would, however, appear that the more porous briquettes yielded by the closing up of the pores. Increased knowledge of the mechanism of the failure of bricks is likely to bear fruit in improvements in manufacture. There have been many suggestions that by a more scientific preliminary purification of the raw material the refractory properties of firebricks might be considerably increased. Great claims were made in this respect for the so-called "osmosis" process. This process has been carefully investigated by Mr. S. R. Hind, as also has the method of sedimentation from a thin slip produced by the suspension of the clay in water by the addition of a deflocculant. The results of the investigation have been communicated to the British Refractory Research Association; the physics of the subject being discussed in detail. This research, though leading largely to negative conclusions, has been necessary in consequence of the claims made for different processes. A short summary only of the paper is presented. While fireclay continues to be our most important refractory, increasing attention has been given of recent years to silica materials. Messrs. Hugill and Rees contribute the first portion of a research on the effect of the repeated burning of lime-bonded bricks. The results of a large number of tests show that the bricks are much stronger if exposed to the heat of the kiln for a longer time, in order to complete the transformation of the quartz into cristobalite and tridymite. In connection with the strength of silica bricks, a communication is presented by Mr. Rees on the deterioration of silica bricks when not stored under proper conditions. Probably most of us are aware that silica bricks should not be exposed to severe weather conditions for prolonged periods. It would, however, appear that it is desirable to give complete protection from the time of removal from the kiln to their use in the furnace. Dr. Mellor contributed some information on the causes of variation in the sizes of bricks and blocks, which, while emphasizing the difficulties of manufacturers in this matter, also gives some hints on the method of obtaining good results. One of the lines of research which the Institution some time ago requested should be explored was to determine the conditions influencing thermal conductivity. A great amount of work has been done on this subject. The communication of Mr. A. T. Green records experiments on sixteen sets of bricks made from the same clay but varying in porosity and in the character and quantity of the grog. As would be expected, the conductivity of material of high grog content (*i.e.*, the porous material) is generally less than in the case of the denser bricks, but at the higher temperatures there is a tendency for this relation to be reversed. The conclusion to be drawn from this would simply be that, from the point of view of conductivity alone, a high porosity is not necessarily a disadvantage at high temperature. The advantage or disadvantage of porosity must be judged chiefly from other considerations. I have already mentioned that the work of Mr. A. T. Dale on refractoriness under load shows that porous bricks do not stand up so well under high temperatures under the load test. I have a letter from Mr. Broadberry with reference to my taking his place as the introducer of this report, in which he says, as Chairman of the Committee, that he wishes it to be made clear that he does not advocate too much porosity either in retorts or bricks. Rightly viewed (*i.e.*, taking all points into consideration) I do not think that the results published lead to any other conclusion than that I have stated.

In connection with this question of conductivity there is a further communication on bricks of great porosity as insulators. Such bricks do not stand up against very high temperatures, and have much small strength to resist crushing. In these days when we are beginning to conserve our waste heat to a greater extent than formerly, such bricks may be extremely useful. Though their crushing strength may be less than one-tenth that of ordinary firebrick, their conductivity is only one-fifth of that of such bricks. Our hope is that the publication of these and other reports of research may not only be of assistance to ourselves, but to the manufacturers of refractories, further enabling them to meet the demands of the gas industry for improved material.

I beg to move the adoption of the report.

Mr. J. FERGUSON BELL [who was temporarily in the chair]: I have pleasure in seconding the adoption of this very excellent report, and we regret that Mr. Broadberry, the Chairman of the Refractory Materials Committee, is unable to be present to put the report before us. His place, however, is very ably taken by Mr. Leather. We all know that whatever Mr. Leather puts his hand to, he does it thoroughly and well. The approval that you have expressed of Mr. Emery's paper when he introduced it, indicates your appreciation of the work that has been done by the Refractories Committee. It is evident from the way Mr. Emery handled the question that he is *au fait* with the manufacture of firebricks; and I should say that this communication indicates the great value of the work of the Committee. Many of us have had experience of the results of disastrous failures in consequence of employing perhaps wrong materials, or of the settings not being treated under proper conditions; and it is very expensive to companies or municipalities to have these failures. I am certain the members will read this report with great interest.

Mr. W. B. LEECH (Beckton): May I add my thanks to the author for his excellent paper. He has tackled a very difficult job, and got through with it in a most capable manner. At the commencement of the paper he sets out the advantages and disadvantages of silica materials. I have gone through these, and I am sure that the advantages are material, and the disadvantages, I can say from experience, are not insurmountable. That you can expect longer life from silica retorts has been proved in practice; and from conversations I have had with engineers in America and on the Continent, this has been supported. One well-known engineer in Berlin stated that he had silica retorts which had had working lives of 4000 days. Some years ago we thought 2000 days' life extraordinary, but he assured me, though I did not have an opportunity of inspecting the retorts, that their life had been 4000 working days. Regarding the other points in the paper, Mr. Emery says that retorts are easily scurfed, that the scurfing period was reduced by about one-third, and that it is unnecessary to use any scurfing tools at all—in fact, I should say it would be dangerous to do so. As to disadvantages, I am of the opinion that very little extra precautions are necessary in re-setting or setting, except for due allowance for expansion; but there is another point, and that is the jointing materials. It is necessary that care should be taken with these. At Beckton we have had one or two experiences in which the retort has become porous through faulty jointing materials, and we lose gas to a considerable extent until they are well carboned. The method of jointing and type of joint are also very important. Tongued and grooved joints, unless they are well made, are sometimes not satisfactory. They require a lot of fitting together. If tongued and grooved joints are fitted, they should be of the best type, with the double groove. I have noticed that it takes a good deal of supervision to get the retort setters to fill the joints properly, especially in these days when bricklayers are scarce and we have to get all sorts of men who require a lot of supervision to keep them in order. Capital outlay is included among the disadvantages, but I think the difference is so small as to be almost negligible. The cost of resetting comes to about 6d. per ton of coal carbonized, and the cost of the extra silica is under 0·1d., so that it is very small; it is hardly worth consideration. I was rather startled at the results claimed at Keighley, and I should like to congratulate Mr. Bromley on the excellent results he gets. It made me think I had gone on wrong lines in asking my Directors to adopt silica; but I can assure you that at Beckton we have not been able to get anything like 2600 days with fireclay retorts. It may be that we are carbonizing a different size of coal, because I believe the size of coal has a great deal to do with it. If Mr. Bromley is carbonizing screened coal, he might get better results for that reason than we did at Beckton with fireclay retorts. I can assure you that working with fireclay retorts at Beckton, with a temperature of 1400° C., the life has not been much more than 500 working days. With silica retorts we are getting 35 cwt. per day, as against 2 tons at Keighley. It is often thought that fireclay is good enough to put on the outside of combustion chambers and division walls and on the outside of retorts. It is good enough as far as temperature is concerned, but I think it is necessary to have materials of even expansion on both sides. It is not the quality of the material as regards resisting temperature that is so important, as its quality as regards resisting expansion. The retorts should be put in a setting so that it will move upwards evenly outside and inside. The paper quotes me as having stated that the difference between the internal and external temperatures should be about 60° C. This is a difficult thing to ascertain, but it was a figure we arrived at in some experiments we carried out; and I was glad to have the figure confirmed during a recent visit to the Continent. I spoke to several engineers in Vienna and other places, and they gave me exactly the same figure.

Mr. G. M. GILL (London): Mr. Emery speaks of the results obtained at Keighley. I have seen the retort-house there, and at the time I made a note that the retort-settings were built of siliceous material. Mr. Emery speaks of fireclay. Personally, I think there is a great deal of difference whether the retorts are made of fireclay or siliceous material. With siliceous material you can undoubtedly work at much higher temperatures than with ordinary fireclay retorts. Early in the paper, the author speaks of siliceous material having a percentage of silica between 80 and 92 p.ct., whereas fireclay would have less than 82 p.ct.

Mr. EMERY: Yes.

Mr. GILL: At Keighley, the temperatures there struck me as very high and variable, and, I should think, quite up to what is mentioned in the paper. At the same time, the charges did not appear to me to be 20 cwt. In fact, they were not, and the figures given me showed they were more like 18 or 19 cwt. The results given are so astounding that I thought it worth while to mention these points. It seems to me that the day of ordinary fireclay for modern retort-settings is largely passed except in the cooler zones of the settings. Surely our thoughts should be directed either to siliceous material or silica. That is really the reason why the figures in regard to Keighley are so high, though they were at first said to apply to fireclay.

Mr. W. S. MORLAND (Gloucester): I have only just received a copy of these papers, and have not had time to go through them. In case it is not mentioned, however, I want to ask with regard to the expansion of silica material. It is generally stated by makers of silica retorts that it is advisable not to close up the silica, but to leave a space for expansion. That may be all very well the first time you light your furnaces up; but when you come to drop them down, you will find that these joints will fill with dust, and then there will be no allowance for expansion. I am not speaking of expansion upwards, but expansion in length. I daresay you might probably get an expansion of probably 2 or 3 in. in (say) a 20 ft. through horizontal retort, which I am referring to particularly, and I should be glad to have some information on this point. There is one other matter, and that is what effect has the nature of the coal on the silica material. As we work it in ordinary retorts we sometimes have spells of rainy weather, and the coal goes straight into the retort. My experience of silica materials is that if you put any wet coal on to it, the sudden cooling chills the silica material and it cracks, and therefore I would like some information on this point also. With regard to joints, I suppose I have had as long an experience as anyone in building-up retorts. At Gloucester we have done it probably for 50 years, and we find that the grooved brick is the one to use. I have used all kinds, but I have found from experience that a brick with a small groove, not larger than $\frac{3}{8}$ in. diameter, and filled with as much fireclay as can be got into the material, gives a result which allows of very little contraction in the setting. I am speaking of ordinary fireclay bricks. I am taking out settings now that were put in in 1915, not because the retorts have sunk in any way or are damaged, but because they are filled up with dust in places that we cannot get at, and we are bound to take them out to ensure efficient heating. From these settings I have been able to make more than 70 therms per ton, showing that we do good work. If I were confident that I could get something which would stand as well as this Stourbridge fireclay material, and would do as good work, I should certainly like to adopt it. From my experience, however, I am very cautious in adopting any other material than that I am using, because I should still have trouble with dust in the flues which one might not be able to get at. If anyone has any information on this matter, I shall be very pleased to receive it.

Mr. H. J. TOOGOOD (Elland): I should like to congratulate Mr. Emery on the manner in which he has tackled the subject. As a designer of retort-settings I believe in the principle that little things make perfection, but that perfection is not a little thing. Therefore, I would like to describe very briefly the design of a horizontal retort setting and show you how I would attempt to achieve this desideratum by the use of silica. In order to give silica its best opportunity, my experience leads me to believe that the combustion chamber should be kept as far away from that inner cone of the flame as possible, and therefore I believe in the elliptical arch. You will notice, also, that the bricks forming that arch are bull-nose bricks, and this enables the silica to offer a big surface to the flame. With square bricks, the flue dust would get into the pores of the bricks and probably tend to bring down the arch. Therefore, to give silica every chance, you should use bull-nose bricks. You will also observe that the keystone of the arch of the combustion chamber and the producers next the arch are of the self-same stuff; there is no flat arch between to push up and cause expansion sideways. Much has been said about the expansion and after-expansion of silica, but I think a great deal of confusion has arisen by using the word "expansion" for the two phenomena. I think the first should be

expansion—*i.e.*, thermal expansion—and that after-expansion should be designated "growth." Then we should all understand each other, and there would be no confusion. Fig. 12 shows you the attempt made to build 95 p.ct. silica settings to-day. You will notice that the side walls are of silica, as explained by Mr. Leech. The side walls are formed of a saw-tooth edge, so that there is a half-inch space left. There is the same expansion whether you use silica or firebrick or siliceous material, and you have only to take into account an extra ½ p.ct. for growth. If you turn to the cross-section, you will see there are tongued and grooved joints. We have built them both ways; but when the setting is let down after it has been working, it will be found that the natural contraction in the mass will set up cracks in lines of their own, which anyone can predetermine, and you cannot get so tight a joint with flat joints as with tongued and grooved joints. This is the one deciding factor of groove and tongue over two grooves. Looking at the retort section there built up—the X, Y, Z, running round the retort—if this can be done it cheapens production from the point of view of the maker, which assists generally; and from the user's point of view it is just as good. The corner block is cut away at an angle of 45°; this again is a small point, but it adds to the resistance offered by the silica to the flame. If it were square cornered we should be polishing the corner of the brick with the upward flow of the flame. The square corner would also complicate the question of drying; but by placing it at 45°. you can dry it without any delicate arrangement, and the workman can get along with his work with all the despatch that his employers can expect. There is one little experiment I am running at the present time, and that is that I have lined a furnace with silica bricks. It seems an outrageous thing to do, but the theory is this—that if we can do this there will be nothing to flux, as there is with fireclay, or cause clinkers to adhere. The little experiment which was kindly referred to by Mr. Emery was with the idea of preserving the brick from the time it left the kiln until it was put into use. If such a dip can be found for these bricks, we could overcome the porosity of silica retorts in starting-up, which would give them a much bigger advantage than they now have, because things do not move in the gas industry wholly on economical lines of efficiency. There is such a thing as fashion even in the great gas industry.

Mr. MIDDLETON: I am a member of another branch of carbonizing—viz., coke-ovens—and I have been interested in silica very much for the last four or five years, both as a maker and a user. I also make the old class of firebrick, and I have collected a lot of interesting comparative data, though the time is too short to place that before you to-day. I should like to mention one point which I think will be of great interest to you, and that bears on the relative thermal conductivity of silica and firebrick. It is impossible to draw any definite conclusions from laboratory experiments. We have during the past 12 weeks set to work a battery of coke-ovens for carbonizing 1000 tons of coke per day, the walls of which are built entirely of silica, and we shall therefore be able to make comparisons between these walls made of silica and older plants built of 80 p.ct. silica. The results so far have been striking. We have reduced our carbonizing time from 27 hours to 16 hours, with a reduction in width of only 3 in. The evidence that I have gathered from America and elsewhere, where the width of oven has been reduced, shows that you get a reduction in coking time of one hour for 1 in. reduction in width. Therefore, crediting the narrower furnace with three hours, because it is 3 in. narrower, we have a reduction in coking time of 6 or 7 hours due to the silica construction alone. The most remarkable point about it is a thing which surprised us most; we have got this advantage without increase of temperature. We knew we could get that big reduction in coking time, but we thought we should have to go to 150° or 200° higher in our carbonization temperature. We find, however, we are working at exactly the same temperatures with the silica as we are with the 80 p.ct. silica. The temperature in the combustion chamber in most cases is from 1380° to 1400° C., and the temperature at the top of the horizontal flow, just when combustion is complete, is 1200° C., and the temperature within the oven walls—reading with an optical pyrometer through the charge hole, and taking the average—shows that there is no variation more than 50 p.ct. Working it out we find there is a 23 p.ct. improvement in thermal conductivity with the silica. It is well known that you can work a setting at much higher temperatures if it is built up of silica. If, therefore, we went 150° higher, we should get a much bigger reduction in coking time, due to the increasing thermal conductivity of the silica at the higher temperature. I should not be at all surprised to find in a little while that we are able to get 40 p.ct. more coal through the silica retorts than with fireclay or semi-silica. There are a few more advantages of silica which Mr. Emery has not brought out, though he has done justice to silica. One is that you are able to get wonderfully accurate shapes. It is possible to make bricks that do not vary more than 1 p.ct. from the drawn size, so that it is unnecessary to do any cutting at all. In the battery I have spoken of we have used 3800 tons of shaped silica, and we did not cut or dress a single piece. The whole lot came together with very fine joints, whereas in the case of 300 tons of fireclay we had to cut every piece, with the result that we spent three times more money in wages in cutting the bricks than we did in making them. Moreover (as you know), the loss of the kiln skin on the brick renders it much more liable to abrasion than if this had not been necessary through cutting. The question of spalling has been spoken of, but in the battery I have mentioned we did not spall a single brick. The old idea of door setting should not be necessary. It is an old idea in steel works. They built all their bricks to the door at one time, and it certainly did save them spalling to some extent, but now it is possible to make the bricks without that necessity, and spalling does not take place. If the bricks were weak, we certainly think it would be an advantage to do this. Reference has been made to long soaking at high temperatures. There are great advantages from the manufacturing point of view in soaking them for 3 or 4 days at 1500° C. You get extraordinary strength and toughness, and you get rid entirely of the bugbear of growth.

Mr. J. FERGUSON BELL (Derby): I am sure we are all very much obliged to Mr. Middleton for his interesting remarks, and we hope that he will supplement them by a written communication.

MR. T. F. E. RHEAD (Birmingham): I should like heartily to thank Mr. Emery and the Research Association for their valuable symposium on refractory materials. There are several points raised by Mr. Emery, which are of intense interest concerning the abnormal behaviour of firebrick material in lasting so well. This is explained in the paper as being due to the fact that the fireclay may be of the nature of silica. I understand that silica stands well up to the mould. The rapid melting-point of pure chemicals is well known, and the gradual softening of mixtures is well known, but I cannot quite see why fireclay mixtures should behave like a pure material. I can testify to the importance of exercising great care in the cement that is used both for silica material and firebrick material. We had some trouble recently with fireclay material which had been reinforced with silica. These bricks tested remarkably well according to the Institution of Gas Engineers specification, and there was practically no expansion or contraction; but it seemed to me that they had not been sufficiently burned. The silica was probably not all converted, and consequently, after a few months, they began to spall badly. There is a big difficulty (as we all know) with the raw materials; particularly with fireclays, which I will explain. We have carried out in Birmingham thousands of tests on refractories, and have found that where the material is on what may be called the border line, though you may take advance samples from the kiln which pass the tests satisfactorily, you are liable, when the consignments come in, to get material which is not right. It therefore seems to me that you want a really good factor of safety in using such a material. It has been my privilege to go over some of the modern works where fireclay materials are made, and where they are using every ounce of scientific knowledge and control in their manufactures. It does seem a pity that gas engineers one and all do not support these manufacturers. Many gas engineers do; but I have often heard it said by manufacturers when they are buying their materials: "What is the use of bothering; people buy the cheapest they can get." You cannot get these high qualities without a little more expense; and I do recommend strongly to everybody that they patronize the manufacturers who are making this great attempt to improve our refractory materials. Mr. Leech mentioned an interesting point about the difference in temperature on the inside and the outside of the retort, and said he had found it to be 60°. That is a remarkably small temperature gradient, and I should like to ask Mr. Leech whether that was just after scaling or when the retort was ready for scaling, because it would make a considerable difference.

Mr. LEECH: I cannot say the exact time.

Mr. RHEAD: Reference has also been made to the life of the retort. It all depends whether the retort has had a steady life or a heavy one. Just to state the number of hours it has lasted is not always fair to the material.

The PRESIDENT: We have had a most interesting discussion on a most interesting subject, and I believe we could continue this for some time. Unfortunately we have just received an intimation from the Institution of Electrical Engineers—whose guests we are—that this building is required for another meeting, and I am afraid I have no option but to ask those who wish to contribute further to the discussion to communicate with the Secretary in writing. While I do not want to take up your time, I do want to express to Mr. Emery our great appreciation of the practical and useful paper and the intimate knowledge he has revealed in the analyses of the samples he has explained; and he would add a further obligation to the Institution if he would be good enough to make his reply to the discussion in writing. This is not the occasion for a formal vote of thanks to Mr. Emery, but I am sure you will wish to express your great pleasure at having the paper placed before the Institution.

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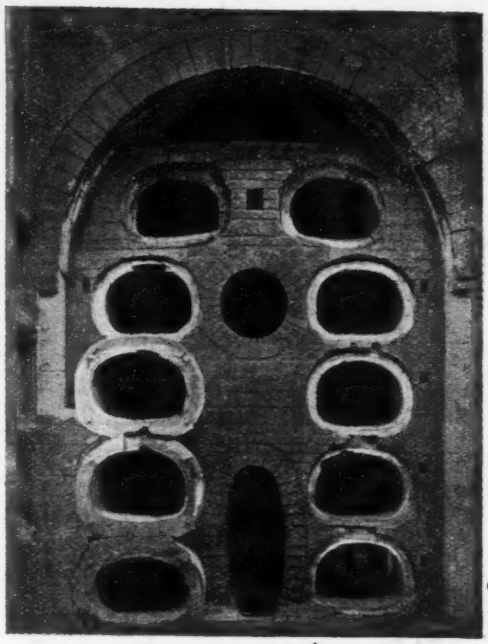

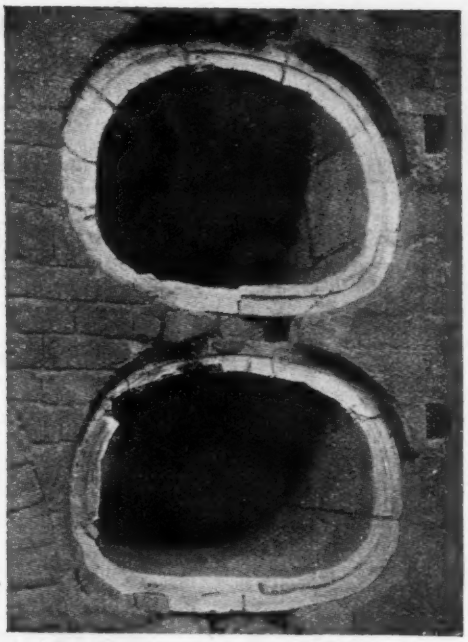

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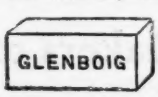
TRADE 

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